PROCEEDINGS

OF THE

Liverpool Geological Society.

SESSION THE FORTY-SIXTH,

1904-1905.

Edited by R. W. BOOTHMAN ROBERTS, F.G.S.

(The Authors having revised their own Papers, are alone responsible for the facts and opinions expressed in them.)

PART I. VOL. X.

LIVERPOOL:
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1905.

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ADDITIONS TO THE LIBRARY OF THE LIVERPOOL GEOLOGICAL SOCIETY, 1904-5.

The usual Proceedings and Transactions of the various Scientific Societies have been received for the Library of the Society during the past Session, also:—

British Museum.—"Catalogue of the Jurassic Flora," Part 2, 1904.

British Association Report, 1904.—Cambridge Meeting.

Geological Survey of the United Kingdom.—"Summary of Progress for 1903."

Herschell, Sir John.—"Familiar Lectures on Scientific Subjects," 1867. (Presented by T. Mellard Reade, C.E., F.G.S.)

Mexico.—Instituto Geologico Nacional.—Tome 1, 1904.

Palæontographical Society.—Vol. lviii., 1904.

Royal Geographical Society.—Extra Publication, "On Recent Contributions to Our Knowledge of the Floor of the North Atlantic Ocean," by Sir John Murray, K.C.B., F.R.S., and R. E. Peake, M.Inst.C.E.

Smithsonian Institution.—Annual Report for 1903.

Transvaal Geological Survey.—Report for 1903.

Whitaker, W., F.R.S.—Pamphlets on Kentish, Surrey, Hampshire, and other Wells.

PROCEEDINGS

OF THE

LIVERPOOL GEOLOGICAL SOCIETY.

SESSION FORTY-SIXTH.

OCTOBER 11TH, 1904.

THE PRESIDENT, THOS. H. COPE, in the Chair.

The following Officers and Members of Council were elected:—

President—H. C. BEASLEY.

Ex-President—THOS. H. COPE.

Vice-President—W. HEWITT, B.Sc.

Hon. Treasurer—W. H. ROCK.

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Hon. Secretary—W. A. WHITEHEAD, B.Sc.

Members of the Council—Messrs. T. H. ALLEN, G. H. ASHWORTH, J. BRUCE, M.A., J. LOMAS, F.G.S., and J. H. MILTON.

Professor W. W. Watts, M.A., F.R.S., was elected an Honorary Member. Richard Forshaw, Beachlands, Waterloo; proposed by W. A. Whitehead, B.Sc., and J. Lomas, F.G.S., was elected an Ordinary Member.

The President, Thos. H. Cope, read his Annual Address:—

"Some Geological Problems in South-West Lancashire."

NOVEMBER 8th, 1904.

The President, H. C. Beasley, in the Chair.

The Meeting was held in the Lecture Theatre of the Royal Institution, and was open to the public.

The following Paper was read:—

"The Lipari Islands and Its Volcanoes."

By Dr. Tempest Anderson, F.G.S.

(The Paper was illustrated with Lantern Slides.)

DECEMBER 13th, 1904.

The President, H. C. Beasley, in the Chair.

The Hon. Treasurer gave his Annual Statement of Accounts, which was unanimously adopted.

W. D. Brown, Homeleigh, Burscough Junction: proposed by J. Lomas, F.G.S., and J. H. Milton; William Chester, Council School, Longmoor Lane: proposed by H. C. Beasley and W. A. Whitehead, B.Sc.; J. W. Collinson, College Road, Crosby: proposed by J. H. Milton and W. A. Whitehead, B.Sc.; Philip Jones, Council School, Venice Street: proposed by J. Lomas and W. A. Whitehead, B.Sc.; James F. Smith, Newstead, Wavertree: proposed by H. C. Beasley and G. H. Ashworth; Arthur Wade, Science Laboratory, Arnot Street: proposed by J. Lomas, F.G.S., and W. A. Whitehead, B.Sc., were elected Ordinary Members.

Exhibits:—

Specimens and Slides of Pele's Hair and Slag Wool, by J. Lomas, F.G.S.

Lantern Slides of Geological Features (British Association Set), by J. Lomas, F.G.S.

The following Paper was read:—

"Notes on the Glacial Geology of Anglesey."

By W. Edwards, F.G.S.

JANUARY 10th, 1905.

The President, H. C. Beasley, in the Chair.

S. E. Gouldson, Council School, St. Michael's: proposed by J. Lomas, F.G.S., and W. A. Whitehead, B.Sc.; Chas. Stevenson, 53, Egerton Street: proposed by J. Lomas, F.G.S., and W. A. Whitehead, B.Sc.;

Miss M. PALJIS, Tatöi, Aigburth Drive: proposed by J. LOMAS, F.G.S., and W. A. WHITEHEAD, B.Sc., were elected Ordinary Members.

EXHIBITS:

Casts of Footprints, by H. C. BEASLEY.

A Contour Model of the Mersey Basin, by J. LOMAS, F.G.S.

The following Paper was read:—

"NOTES ON SOME SPECIMENS OF BOULDER CLAY."
By T. MELLARD READE, C.E., F.G.S., F.R.I.B.A.

FEBRUARY 14TH, 1905.

Mr. THOS. GOFFEY, in the Chair.

The following Papers were read:—

"NOTES ON A FAULT-FISSURE AT INGLEBOROUGH."
By HAROLD BRODRICK, M.A.
(With Lantern Illustrations.)

Report as Delegate to British Association, by J. LOMAS, F.G.S.

FEBRUARY 28TH, 1905.

THE PRESIDENT, H. C. BEASLEY, in the Chair.

The following Paper was read:—

"THE PHYSICAL FEATURES AND GEOLOGY OF BRITISH EAST AFRICA."
(With Lantern Illustrations.)
By W. McGREGOR ROSS, B.E.

MARCH 14TH, 1905.

THE PRESIDENT, H. C. BEASLEY, in the Chair.

SIDNEY SLATER, 12, Agnes Road, Blundellsands: proposed by H. C. BEASLEY and J. LOMAS, F.G.S., was elected an Ordinary Member.

The following Paper was read:—

"NOTES ON SOME PHYSIOGRAPHICAL AND SURFACE FEATURES OF THE LAKE DISTRICT."

(With Lantern Illustrations).

By E. DICKSON, F.G.S.

APRIL 11TH, 1905.

THE PRESIDENT, H. C. BEASLEY, in the Chair.

W. H. BARLOW, 134, Prenton Road West: proposed by J. LOMAS, F.G.S., and W. A. WHITEHEAD, B.Sc., was elected an Ordinary Member.

EXHIBIT:—

Lantern Slides of Mount Pelée, by J. LOMAS, F.G.S.

The following Paper was read:—

"SANDS AND SEDIMENTS" (PART II.: GEOLOGIC SEDIMENTS OF MARINE, ESTUARINE, OR FRESHWATER ORIGIN).

By T. MELLARD READE, F.G.S., F.R.I.B.A., and PHILIP HOLLAND, F.I.C.

FIELD MEETINGS :—

1904.

May 28.—Hilbre Island.

Leader—Professor HERDMAN.

June 25.—Doulton's Delph.

Leader—W. A. WHITEHEAD, B.Sc.

Sept. 3.—Hope Mountain.

Leader—H. C. BEASLEY.

Nov. 5.—Hale Point.

Leader—J. LOMAS, F.G.S.

THE LIVERPOOL GEOLOGICAL SOCIETY, in Account with W. H. ROCK, Hon. Treasurer.

Dr. SESSION 1903-1904. **Cr.**

Dr.	£	s.	d.
To Rent, October, 1902, to October, 1904..	10	0	0
,, Tinling & Co.—Stationery for Session.	6	1	0
,, Walmsley— do. do ...	0	6	6
,, Tinling & Co.—Printing Proceedings (not completed)	0	0	0
,, Mrs. Ellick—Teas and attendance, &c.	6	18	0
,, Secretary's, Librarian's and Treasurer's Expenses	3	7	1
,, Geological Magazine for Session	0	18	0
,, Palæontographical Society, 1904	1	1	0
,, Reproduction of Mr. J. J. Fitzpatrick's Portrait................................	0	9	4
	£29	0	11
,, Balance to carry forward	14	13	9
	£43	14	8

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By Balance from Session 1902-3				0	11	8
,, Subscriptions, &c., received :—						
1902-3—Arrears	£0	10	6			
1903-4—Subscriptions ...	37	16	0			
Printing Fund	0	18	0			
Proceedings sold	0	15	6			
1904-5—In Advance......	3	3	0			
				43	3	0
				£43	14	8

Audited and found correct,

(Signed), E. DICKSON.
H. CAPPER.

(Signed), W. H. ROCK,
Hon. Treasurer.

Liverpool, *8th October, 1904.*

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READE, A. L., Park Corner, Blundellsands.
SCHOFIELD, H. H., 53, Fern Grove, Lodge Lane.

* Have read Papers before the Society. † Contribute to Printing Fund.

SOME GEOLOGICAL PROBLEMS IN SOUTH-WEST LANCASHIRE.

PRESIDENTIAL ADDRESS,

Read October 11th, 1904,

BY THOMAS H. COPE.

INTRODUCTORY.

When, in our last Session, I had the honour of addressing the Liverpool Geological Society on the subject of some "Flow Structures" in Nature, my intention was to follow the subject, in more minute detail, in this, my second year of office as President.

This intention has been modified, and it appears wise to abandon specialization in favour of a subject of greater utility and importance: the consideration of acquiring a deeper general knowledge of that portion of the County of Lancashire of which our Society, centrally situated as it is, should be collectively the best exponent.

The few preparatory remarks, which fall to my lot to make, need not detain us.

One sad duty is to allude, with sincere regret, in which assuredly the whole of our Society participates, to the loss sustained by the death of the late J. J. Fitzpatrick.

An ardent geologist and author of many original papers, given before this and kindred societies—he was taken from us in the prime of life.

At the time of his death, many scientific bodies beheld with esteem his name upon their roll of active members. Of one of these he was President, and had already prepared his Annual Address. The anxiety of its delivery was left to another to so complete that life-work, in which he had taken such deep interest, and on his understudy devolved the task of yielding to the world the results of long months of labour expended on the author's well-beloved subject.

Our Society maintains its high status, with an augmenting degree of strength, numerically and financially.

The stability of a scientific body rests entirely with its members. On this score your Council will be the last to complain, but if the suggestion thrown out in this address bears fruit, a far better cohesion of mutual interests should be looked for in the future.

In such a country as ours, and with our own Society in its midst, individualism in work should be a thing apart. Reciprocity of interest is unquestionably necessary, and work should be conducted on a communistic basis; the greatest results from the greatest number.

We, as a body of Liverpool geologists, succumb to the temptation, as individuals, of working in specialized grooves which our sense-perception assures us is the work we are most specially adapted for. Probably we are wrong. More valuable would be the results of scattered energies concentrated upon a platform of geological research, hitherto rather neglected in this territory.

Most of us have a bias in geological work. This is perhaps as well.

The individual predilection for the pursuit of specialized knowledge leads to a more thorough conception of the subject as a whole, when work is correlated.

The results of such research, brought into harmony with each conflicting theory which alienates different branches of study, must be valuable, and these "side issues," adapted to general principles, should produce valuable results in any scheme of possible co-operative work.

Many are the methods by means of which the complete geology of a district may be examined and worked out.

A certain discouragement must prevail as each new volume comes from press, signed by well-known writers, who have, perhaps, annexed our chosen area for their sphere of activity. One is predisposed to say, "it is finished—further research is futile; let us be pioneers in some new field."

Later workers, as yet undismayed, discover clues and facts hitherto unobserved, and it is here that the courage of conviction triumphs. Old tenets set aside, the new observer discards ancient history, and applies himself to the task of erecting an edifice which shall be both final and enduring.

One worker might do much; but how much more might he accomplish were he aided, by the efforts of a Society such as ours, in a scheme where the labours of each and all should be inter-dependent, but yet concentrated upon the combined result of knowledge resulting from such a task?

Geological history thus undergoes a new analysis, a further dissection, and new facts are revealed where once the chapters were considered entirely closed.

So will this history be built up along a line of progress by a constantly increasing mass of detail, until down the years, centuries ahead of our time, a future generation of geologists will say, "even now there are problems yet unsolved;" for never will the complexity of our small world's outer crust be completely understood.

Individual work gives scattered results. It does not

come before us in a concrete form. Rarely is the work so cemented by mutual help and free intercourse of ideas, that classic problems may be reduced to a solution acceptable to all.

Consequently, some confusion remains; nomenclature, specimens, localities and mapping, all differ in collected records, and an attempt at correlation is usually abortive. No doubt, however, may be cast upon the merit of the individual work performed, or upon its ultimate scientific value.

The break in the line of scientific continuity is that which shows by default the necessity of co-operation of interests.

The chain of evidence has been forged, many are the links pieced together. But, also, many links are missing. Who are the finders?

The geologist who drifts out from a tangle of miscellaneous work (those stepping-stones to higher knowledge) awakes at some time to the fact that his sustained interest in the "Study of Rocks" is due to the fascination exercised by the seductions of some special branch of the study, and the newer the theory the greater the attraction.

These special lines of investigation, standing alone, form an important integral part in the geological history of past ages, and from which many chapters of the present day may be compiled.

There may be other methods of perfecting our general geological knowledge of a region. One of these could take the form of investigation conducted upon co-operative lines.

It is, with some such idea in mind, that the present Address takes the form rather of suggestions than dogmatic certainty of observational results. The hope is latent that such suggestions, in time to come, will yield useful scientific results.

The District.

The flatness of the region to be discussed is revealed by a casual glance at the contour map. In a few places only does it rise above the 200 feet elevation, and from the monotony of flat curves there might appear to be few features of interest to the geologist.

As to boundaries—westwards we have a confused mass of sand dunes, as a seaward limit; the Ribble to the north, the Mersey south, and the Anglezark hills eastwards. This ceinture contains geological possibilities which, to the philosophical thinker, must be replete with problems of no ordinary kind and of abiding interest.

This is one of those corners of the world, perhaps somewhat neglected by the student, where physiographical geology, even if neither heroic nor classic, may be found to be informing, educational and useful. Of necessity there must be inferred geologic deductions whenever the land surface appears above sea level, but in this territory, perhaps, the science of pure geology is largely merged into those of physiography and geography. The delineation and history of the actual land surfaces becomes even more important than that of purely stratigraphical relationship of horizons, and the known land lost in historic times. The "hammer" may most often be regarded as an "insignia" than as a necessity.

Sandhills and Dunes.

A prolific source of minor problems should be that wide expanse of classic desert, the Formby sandhills, the great tract of æolian formation which has been erected in historic times,* and is young in geological history.

* Probably later than the 14th Century.

What is their life story, and why the sharp truncation separating them from the flat area landwards?

Changing day by day, what are the lessons they teach us?

The bodily movement of individual hills, their growth and decay, the attrition of polished quartz-grains, protection of sand cliffs, salients produced by matted "starr-grass," the sifting of heavy material by sub-aerial action; also the laws regulating sand-sculpture, by which the prevailing directions of winds may be estimated; these are some of the questions which arise.

What is the origin of this sand? Is it from the local Trias, or brought down from the uplifted Millstone Grit?

Again, what the reason of its futile heaping up between the estuaries of two large rivers, and forming a salient of accretion? Is this a true "cuspate foreland?"

The study of past and present drainage systems may throw light on these problems.

Other questions take the form of comparison between the dunes and the foreshore off Formby Point, the sand on the Mersey Bar, and that in the channel of the Ribble.

A determinative analysis of these sands suggests many useful results to be obtained in the field, and known methods of fractionating by heavy density fluids, discounting tide and wind sifting, would assuredly reveal a clue to the original source of origin of them all.

Another point to determine is; where is the differential margin between marine, fluvatile and blown sands? To have these boundaries mapped would be indeed a useful work accomplished.

Sand dunes are the inevitable results of estuaries. Those who live on their borders should be most capable of probing their mysteries.

Coast Erosion.

While the Coastguard have a general instruction to observe the erosion of land borders, or inversely the accumulation of detrital material, it must be assumed that such unofficial duties can be performed but in a perfunctory manner: the scientific interest cannot be in evidence.

It becomes essential then, that those more deeply interested should control the records, that trained geologists should take up, if necessary, an official responsibility of recorded observation—and who better fitted for the task than the members of our own Society?

Former continuity and present loss of land is a subject which can now only be briefly touched on. There is also another development of the question—the present invasion of the land seawards.

In the first case we can say little. The land connecting the Isle of Man with England and Ireland has disappeared. The second is of more importance, and the attention of students of Pleistocene times may be drawn to the enormous waste of land, removed from fertile inland soil to form barren mud-flats and sand-dunes.

Our rivers are muddy. They contain a vast amount of silt. A muddy river implies that Earth is impoverished by the sea; it also betokens one of the greatest of national losses.

Rich soil, formed by disintegration of solid rock, is washed away into the ocean to form an unprofitable secondary land.

It is contrary to public policy, or at least to the welfare of the future, that fertilized "top soil" should be sent down to the sea and lost. This is a problem affecting the science of geology. A remedy must be found. Probably this might be simple re-afforestation, a task

surely within the scope of the practical geologist, and his advice should be sought.

Lesser questions here occur which include those of channel silting, and the vexed problem of sea displacement by the piling up of river detritus.

Expert geological knowledge could deal in a more satisfactory manner with such matters than the civic authorities of belligerent townships.

Probably all our present day muddy rivers ran clear before the advent of civilised man, and this we must not forget.

An opportunity is thus afforded to investigate the past and present of our coastal line, and to make such dispositions as will render our Society the first authority and final Court of Appeal in every question pertaining to the marginal changes of our ancient continental seaboard.

Ancient Meres.

The probable life-history of many mosses has as yet received little attention. While each mere has had an individual and independent existence, it is obvious that, as their origin was dependent upon the stage of glaciation and system of drainage which then prevailed, the circumstances of origin must have been common to all.

Their correct survey, former limitations, conditions of the island platforms in their midst, the levels of actual floor, whether above or below present sea-level, and the depth of the infilling peat whose present level surface betrays the superfices of the old lakes, are necessary points to determine if we wish to follow out the history of the mosses to its logical conclusion.

Little has been chronicled regarding the origin and decay of these old lakes, much less of their present state of dryness. Before the problem is fully solved the whole of

south-west Lancashire must be mapped, to show the former boundary of every mere and lake, their former inlets and oulets, where these existed in glacial times and their present-day position. Further, complementary horizontal sections would be necessary to complete the work.

Many of these fresh-water basins are to-day well defined after heavy rain, and assume the marginal contour of an age long since past.

The writing of the history of the old Lancashire meres, with our present knowledge of glaciation, has been too long ignored. The need is pressing, and this Society should be the pioneer historian of their true record.

Present records must be systematized, and the delimitations of these old pools—which are now only revealed to the practised eye—should be carefully plotted.

The physical history of these lakes, now Chatmoss, Martin Mere, Risley, Carrington, King's and Simonswood Mosses, also Leasowe, Altmouth and Liverpool, of necessity invokes some aid from Archæology, which we should not entirely decline.

Other considerations are the cause and origin of the present great depth of peat, and the climatic conditions then prevailing.

A thorough enquiry into the formation of our peat mosses appears to contain strong possibilities of new discoveries. It should prove a fascinating study.

The moss which absorbed the material derived from "Olive Mount" cutting* at Broad Green, and even then leaving no stable foundation for a permanent way, should be the first upon which the searchlight of science should be shed. The rock bed of at least this mere must be far below sea-level.

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* Smiles' "Lives of the Engineers."

There is a matter for the cartographic geologist also to determine—the parallelism of the under-sea landscape with that of the floor of this Chatmoss and other lakes—the divisional coast line and its meaning.

It is known that within historic times, there have been formed lagoons of fresh water due to the damming up of stream outlets. But there were other causes for lake formation. It is for us to seek them.

Subwaters.

From whatever cause, peat appears to be the highest platform, over a large area, which might be considered as solid rock. The covering "blown-sand" assumes the features of a certain state of false-bedding of strata and takes the position of the latest layer of construction.

Along divisional planes, between sand and peat, ride the subwaters, the land drainage by subterranean channels on its way westwards. We know little of this underground river system. Perhaps it is partly responsible for choked river channels by drifted sands.

Flow volume of sand ascertained, experiments as to depth, from a land surface, and climatic influence on water supply, might result in practicable application of methods (guided by geological inductions) by which many agricultural and sanitary questions would be satisfactorily met.

The sub-water question is one which merits closest investigation and which may be found to exercise an important bearing upon the health of such low-lying coastal towns as Southport.

Changes in Land Level.

The slight elevation of this tract of country may be partly due to some degree of subsidence, but we must not

overlook other possible agents associated with the disappearance of solid land. More detailed work than we have at hand will be necessary to prove, say, the former existence of a connecting link with the Isle of Man, or even Ireland.

On all sides can be seen forestral remains, now represented by "mosses," moorlands and under-sea forests. Whither do the latter extend and what is the area of their former extension?

Was it a huge catastrophe which swept away by ice or flood these primeval woodlands and buried them in swamps or lagoons, or a subtle invasion of fresh-water sheets and the breaking of their dams, which flooded all low-lying areas? Of all this we have little record, but the testimony of the pleistocene peat is at hand, and the chapters of the past lie before us, even as an open book.

It has been said that no document is so untrustworthy as a mediæval map, and perhaps with some degree of truth. Nearly all agree in delineating the coastal line much farther seawards than that which obtains at present. We have hardly grounds for asserting that such maps were not as correct in their generation as the Ordnance Survey of to-day. Especially is this applicable to those of Roman origin.

Ptolemy's* map is undoubtedly faulty from a cartographical point of view; but can we say that his mapping of the coast line was not correct in his own epoch? Sufficient is it that present day fathom contour lines fairly well agree with shore lines as laid down by the Roman astronomer, during the period of the Roman occupation of Britain. The line of land lost in historic times lies far nearer the land than that of Ptolemy's delineation.

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* Ptolemy's Map of the British Isles: from Roy's Military Antiquities of the Romans (early in the Fifth Century).

Four kinds of forces influence the depression or elevation of terrestrial levels:—

(*a*) Cosmic movements arising from deeply seated internal action, intermittent, gradual or sudden.

(*b*) Local subsidence, unconnected with the initial action of internal forces, from the release or removal of loose substrata by water action or strain-slip of looser strata over impervious clays.

(*c*) Sea erosion; the fretting away of least resisting earths and rocks.

(*d*) Denudation by rivers or sub-aerial action.

It is for us to inquire into and investigate in what measure these forces have been instrumental in moulding our coastal line to its present form.

There are many lost towns on the ancient coast line from Morecambe to Harlech. Some important ones in our district were Lowscales, Aldingham, Singleton Thorpe, Wadden Thorpe, Altmouth and Meols. What is the true history of their disappearance?

This branch of study is not exhausted. It may be commended to the thoughtful as being prolific in fascinating problems. But as yet we are not thoroughly equipped with the knowledge of the rate at which we are being deprived of our heritage of solid land, or inversely of the rate of accumulation of new possessions.

Sea-charts.

The subject of lost lands, submerged tracts and coastal line is indissolubly connected with the science of Hydrography. Its aid must be necessary to prove a former continuity of land in any seaward direction.

The charts of the Irish Sea leave nothing to be desired in accuracy of detail. Marked soundings are innumer-

able, and nowhere between our coast and the Isle of Man is shown a greater depth than 70 fathoms, which is significant.

The mapped depths lend themselves admirably to the creation of a contour, or better, a relief map, and the hydrostatic curves protracted should end all controversy concerning denudation versus submersion. Land depressed in fairly deep water suffers little deformation during a prolonged period, while signs of denudation on such rocks before submergence are always clearly to be perceived.

This map would assuredly show indicated river channels, old courses and estuarine margins long since covered by the sea. It would throw light on questions of denudation by "ice-scour." Were all these forces working in unison? If not, which was the most potent agent in the forming of the shallow sea? This map might tell us the story.

Was the United Kingdom actually united before the advent of the ice, and our Islands joined together by common territory, as depicted in ancient maps? It is difficult to credit the possibility of ice-scour causing entirely the present dis-unity.

Here we find open a vast subject for inquiry, in all its phases.

River Systems.

This alluvial plain of south-west Lancashire suggests but few problems when we come to consider the question of natural drainage. Eliminate, however, from the map all details which mask the river system and many a problem worth solving becomes developed.

We now obtain a skeletal river map, an admirable exposition of an ideal drainage system which has nearly reached its base-level of erosion. Drainage

past and present has been greatly influenced by the ice which formerly occupied this country.

Glaciation was the cause of the change of the watershed formerly prevailing and probably deflected the current of many important streams.

Rivers on their nearest way to the sea westwards, held up by ice sheets, with consequent formation of fresh water lakes, suffered reversal of their drainage and were compelled to resort to more hospitable channels in an easterly direction. The ice forced natural drainage back as far as the Anglezark anticline, and yet further to the Pennine Chain, where we find to this day ancient dry channels signifying an eastern drainage. A new line of watershed was thus formed.

Coast and land borne marginal ice resulted in the impounding of fresh water as meres, and these completely altered the trend of river flow, thus laying the foundations of new watersheds.

It must be assumed that (1) normal drainage flowed formerly into the Irish Sea; (2) that the ice invasion checked the outlets, and that (3) the sky-line of watersheds underwent modification with resultant alteration of catchment basins.

The present drainage system is fairly normal, but what conditions obtained when the ice lay high in the Irish Sea, checking the seaward flow of streams? Was the Ribble compelled to change its course and find a passage through the Forest of Rossendale?

The present open mouths of our low-walled "fiords" of the north, the Dee and Mersey, were probably not then in existence, it was at a later period when these rivers breached, in combination with sea action, the low bank separating them from tidal waters.

We still require corroboration that the Dee-Mersey depression was nothing more than a post-glacial diversion,

for there are still problems to be faced on the drift map which might prove the Mersey at least to have had several independent channels, in long divided periods of time.

One problematical outlet, now obscured by drift and a little above O.D. goes through Widnes by Huyton to Formby. Another over Chatmoss through Wigan to the coast near Southport. It is clear that the Mersey was the last important stream to break down its barrier and flow in its present channel over the floor of its ancient forests.

The Mersey from its source east of Stockport, is a canal-like stream of little interest as far as Warrington. The sudden enlargement of its course near Widnes, and the broad pool ending at Crosby Channel, signifies something more than an ordinary channel of erosion, or even of ice-scour.

There are several points of interest to be considered in the Liverpool district. Wallasey Pool and the Great Float are sometimes wrongly supposed to be ancient outlets of the Mersey. The "Sea Lake" and "Sea Pool" on the Liverpool side, in the year 1226 are mapped as considerable rivers, the latter as one rising in the heights of Everton. These can only be considered as tertiary streams flowing eastwards from the lagoons formed by the detritus of the ice-block.

Pre-glacial Britain as a solid land would be of a mountainous character connecting Ireland and Scotland, surrounded by a flat plain joining up Scandinavia and the French coast on the south-east and extending some distance into the Atlantic on the west.

The drainage of the Lancashire forests must then have been to the west, and towards the edge of the continent.

As a simple proposition, let us say that the Irish Sea was glacially "scoured out." The south-west Lancashire streams preserved their course until blocked by sea-borne

ice. Drainage checked, stream direction was reversed and flowed landwise, with consequent formation of meres, whose outlets excavated those valleys eastwards which we now recognise as a secondary drainage system. With the ultimate melting of the ice came the release of impounded waters, also an effort to revert to ancient channels. Whether the streams succeeded or not must be one of those philosophical questions which remain as a legacy for our Society to determine. It is still left to the serious minded to further plan out our rivers of to-day in comparison with their evolutionary prototypes of past ages.

With a former westerly drainage, more or less as it is to-day, there was a hiatus between the epochs, an interregnum when normal flow was in doubt as to its natural direction and when drainage piled up into lakes, with an eastwards overflow.

The great height of the ice and sub-consequent alteration of watershed, deflected normal drainage in an opposite direction. The history and determination of these post-glacial channels is one of our greatest problems, upon which much work may be profitably expended.

A natural question may be asked: If the normal westward flow of drainage was effectually blocked by the ice, is it not possible that the warmer land waters would find a passage under this and that normal drainage would to some extent prevail? But to what extent?

Information regarding the "swing" in river courses should enlighten us as to the law-abiding methods of streams in this district, their levels and destructive power. To those learned in these laws we look for elucidation of many river problems, in so far as they apply to our present subject.

The present land drainage suggests some minor problems of curious importance:—

(*a*) The Douglas river flowing north into the Ribble receives eight tributaries from the north-east, but why none from the south-west?

(*b*) The hydrostatist must regard with interest the cases of river-capture; some by natural methods, others artificial. There are cases where streams are captured by reservoirs, by canals, and by dying out by capture of sub-drainage. The line of normal watershed has its effect on these problems, and a 50-foot bank almost anywhere might determine it.

(*c*) The Mersey captured several times by its own river, and permitted later to resume old channels by the Canal authorities, gives us in some measure an idea of its former course.

(*d*) The Irwell, in the Manchester area, disappears in Salford locks, yet it is still mapped as an affluent of the Mersey, near Warrington. This must be a river of secondary origin with a secondary source.

In the Otterspool district of Liverpool are three deeply cut dingles facing south where the map of 1225 showed strong streams running into Liverpool Bay. Then we have the "Sea Lake" and the "Pool" on the same map apparently arising from some river rising north-east of Liverpool.

I agree with Mr. Lomas* that most of these southerly channels were due to a reversal of drainage eastwards, and before our present streams felt their way again to the sea. More especially must this theory appeal to us since there must have been a torrential drainage to the west on the melting of the ice. The history of river deflection,

* The Coasts of Lancashire and Cheshire—their forms and origin.—Proc. L'pool Geol. Soc., 1903, 1904.

capture and general re-distribution of watersheds must be a chapter for the future, and one which I trust our Society will have the first chance in the writing.

Within the limitations of time in the solution of some of our problems, enters the spirit of commerce. The aid of geological science here might again be invoked.

The instinct which placed Liverpool upon the banks of a tidal river found a parallel at Preston. Towns like St. Annes, Lytham and Southport, of secondary origin, built upon estuarine margins and damaged by silting, can have no hope in eventually participating in any important commercial development. How far back was the birth of that instinct? Does history throw light on the Dee-Mersey depression, and will present day history credit that this still continues? Were the ancient villages deliberately planned upon the margins of these old basins —or did later submergence bring the hamlet to the pool? There is work for a lifetime in the answering of these questions.

A last question is "what is the influence of the Formby Point upon the indraught of the Ribble and Mersey—channels now only half a mile apart, whereas the actual river mouths are nearly 17 miles?"

Glacial Striæ.

In rare cases are these recorded on the survey maps. It would illumine the question of ice-movement were a more systematic examination of the district undertaken.

Our studies in the glacials and post-glacials of Lancashire have hardly yet begun. The subject is not new but is full of great possibilities. The few facts already gathered together are inadequate to indicate even the problems to be solved.

From closer mapping of glacial traces, we should obtain better knowledge of the extent and direction of the land-ice, and its connection with that portion of the sheet where the sea now lies—possibly an idea of the period when the ice receded to the sea margin, leaving its legacy of meres. If the ice occupied much of the land area (and nothing but observation of glacial traces can determine this) it seems difficult to conceive a reversal of regional drainage, for sub-glacial streams would still seem possible.

Presupposing the ice to be lying high on the land contemporaneously with that in the sea-channel—where can we place the period during which the old lakes were formed?

Was this process intermittent or were the meres formed towards the end of the ice occupation and when it receded to the continental border?

In theory the scheme of land sculpture and alternations of drainage, by a few elementary propositions, appears to be very simple. It is only when the complex history comes to be written in detail that we recognise how little we know of the truth and how little of the vagaries of natural forces that, we argue, must be stable because their deviations from the normal are neither recognised nor understood; yet how small a change may disturb their equilibrium.

Petrology.

Absence of solid rock in sitû implies difficulty in obtaining satisfactory typical petrographical rock slices. The light we require shedding upon the history of sedimentary rocks can only be obtained through the medium of the microscope, and by the systematic study of progressive alterations in such rocks. Probably one devotes too much time to the study of the volcanic complex in

other regions and too little to its detrital results in this territory.

Several lines of research are open to the petrographer in this district.

" Boulder study " should be of extreme interest. Far travelled " erratics " are informing as to size, nature, origin and direction of an ancient ice-sheet. By petrogical science every boulder should be recognised, and the country of its origin determined.

Mr. Lomas discovered an erratic near Martin Mere, which I should unhesitatingly suggest was the " Glassy-Augite-Andesite " of Ardnamurchan Point N.B. If this is proved we have, at least, a certain portion of the ice track well defined.

There are boulders in profusion in the moss-area. If our east coasts are prolific in Scandinavian " erratics," there is no reason to doubt that similar allothegenic rocks should be found on the Lancashire area of depression.

Boulder mapping and classification should form a chapter of its own, with possibilities of interesting speculation.

The sedimentary rocks will never be known until put to microscopic tests, thus may derivative origin be arrived at. Many tectonical geological questions depend upon the testimony of the " crossed nicols."

The microscope may reveal to us the relationship of the Millstone Grit and the sandstones of the Trias—with the estuarine coast sands.

Friability of sliced rocks in the coal district renders their study difficult, but this may be overcome. Let me now impress upon you the importance of the fact that there is a true key to the understanding of the sedimentaries, and that is the polarising microscope.

The philosophical classification of rocks still makes little progress towards a method acceptable to all, and

especially does this apply to rocks of arenaceous or argillaceous origin.

The horizons of the Tertiary rocks are connected by almost insensible gradations and strongly drawn divisional lines cannot often truly correspond to Nature.

Needless to say there is abundant work to be done in this division, and I would argue that the mechanically formed sediments and their history deserve well at the hands of the microscopist. Should he combine his labours with those of the chemist the work should be exhaustive.

Solid Geology.

Drift obscures the greater part of the land- thus the opportunity is small for determining important relationships of stratigraphical horizons. Still some opportunities are given, but the hoped for solutions to many problems remain as yet in obscurity.

Borings and pit-shafts in local coal-beds, yield prolific studies in stratigraphical geology. Without these aids the chance of gaining information in the coal measures would be indeed a negligable quantity, as inductions at the surface are usually unsatisfactory.

Strike and outcrop seldom emerge from the peat and drift, but there occur instances where the land may be tapped and observations made. When this happens there are difficulties to create and to solve.

If we credit the supposed fact that much of the newer midland rocks have been formed from the detritus of decaying Welsh palœozoic mountains (an island probably at this period), where shall we look for the origin of rocks of the Triassic period? Did not this disintegration of Silurian rocks play some part in the formation of secondary and tertiary formations, north of the Silurian tract?

The origin of the Bunter quartz-pebble beds involves many theories. Petrology here would be a distinct aid.

The Survey sheets, when doubt occurs, map dotted contour lines only, and such boundaries are more frequent than those continuously lined. Much is necessarily inferred. The drift maps show the difficulties to be surmounted.

Sufficiently well as the Survey mapping has been done it is a record of a ground plan only. Any inductions therefrom constitutes a new chapter, the paragraphs of which we must fill up by close application to field-study.

We must decide upon the hiatus which causes the abrupt change between the Bunter pebble beds, the sandstones and marls and the faulting into the coal measure series.

In what period was this transition effected? and when were formations so divided as to eliminate intermediate beds without one trace of their existence as strati-graphical sheets in their proper order?

Petrographical differences between Keuper and Bunter are not the least of the problems. There is a shadow of kindredship here, and this also applies to the two main divisions of the Bunter—the upper mottled sandstone, and the pebble beds. There was a common origin for these rocks, but what influenced their selection and deposition?

The sudden disassociation of coal measures with the Trias leaves much to be determined, and gaps caused by intervening beds necessitate study regarding the failure of chronological succession. The torsional folding of south-west Lancashire demands much research at the hands of our Society, and it possesses the ability to work this out. The country requires mapping as in the past before we invoke the aid of horizontal sections to show us the confusion of to-day.

Work in the field and large scale mapping must be our goal. The problems in solid geology have still rich

gifts to award, but they are too numerous to be entered upon in this address.

The complexity of the subject must be left to the diligence of the student, and I must appeal to his intelligence to mitigate that drastic scheme of inordinate faulting, as presently mapped, and to substitute, when possible, more simple logical inferences for many perplexities.

Conclusion.

I do not set the foregoing ideas upon the pedestal of originality, but rather seek to indicate the value of concentrated thought as applied to co-operative work, and the utility of some such scheme in the future.

The subject is one of the past and present—the history of changes not yet written and the gap lying between the uncharted land of past ages and our heritage of to-day. These suggestions refer more to future work than problems immediately to be solved, and it should be the ambition of our Society to be the pioneers in research work on original lines, in this region. There are questions not yet answered and those still unasked, of great interest, which if not attacked by our members will be encroached upon by other scientific bodies at no late date.

It is a simple task, but one involving diligence and research, to draw together the threads of other's labours. But consider the triumph of annexing a district, working it out in all its details, and delivering a judgment that even if it should not be final, leads towards truth.

The primary hope of this Address has been to indicate the valuable scientific consequences resulting from the efforts of a body of workers, pooling their work in a given area, sifting each detail, discarding old theories, and accepting others, until, of the residuum, some concrete form of value would take shape.

We must sacrifice a little of the "ego" in our "cosmos" to a helpful and common end, and individual energy must be devoted to the consummation of a task which rightly belongs to us.

In the closing lines, let us concentrate or reduce to some intelligible form, conclusions forced upon us.

Problems and solutions must be brought into line and correlated, and into the hands of a responsible Committee —foreshadowed from the first.

The points I offer must be accepted in the spirit of suggestion. There is no implication that the region has been neglected by geologists, but rather that there is more to be done than has ever been essayed. Should the work be seriously taken up I would prophecy a result even of more importance than that of the Trias Committee. We need mutual help—no one worker can solve the whole.

Let us leave behind isolated chapters and re-write them. Let us combine fragmentary specialised effort with a united method of working on selected lines sufficiently interesting to each worker.

Initiative would develop under the stimulus of careful and critical examination of facts perceived. The stamp of individualism must be placed upon each recorded chapter, that in the end a due measure of appreciation and merit should obtain recognition in its own sphere of usefulness.

It is necessary to co-ordinate in the mind the complex facts which go to complete the fabric of the whole, and to so correlate their minutiæ of detail with the broader principles of physiographical geology.

Individualistic selections of lines of research would naturally follow, and would be instructed by intuition. A predilection for any branch of study, would yield more valuable results than were the subject uncongenial.

It must be the wise spirit of choice in this electicism which must select as constituent elements, whatever is best in these suggested problems, accepts and blends them, so as to compose a whole of infinite variety, which is Nature herself.

It is for us to garner in that crop of facts, which goes to make up knowledge; a comprehensive unity of detail which shall be the reward of accurate observation and "The harvest of the quiet eye."

THE GLACIAL GEOLOGY OF ANGLESEY.

By W. Edwards, F.G.S.,

University College, Aberystwyth.

Read 13th December, 1904.

The surface of Anglesey is undulating, the prevailing trend of the valleys being north-east and south-west. All these valleys are filled with deposits of drift often of great depth. Mr. Greenly mentions the Vale of Llanfaes, near Beaumaris, as being filled to a depth of 100 feet, and another in the same neighbourhood to a depth of 60 feet.* It is clear that the rocky bottom of Gors Ddygau, or Malltraeth Marsh, is 60 feet or more below sea level, and filled with much drift. Other valleys, such as that of the River Braint and Alaw, are clearly full of drift.

Inland exposures of any depth are not often met with, but fine sections can be examined along the coast, and from the study of these it is, I believe, possible to get a fair idea of the nature of the drift all over the island.

A section of drift nearly a mile long can be observed at Tal-y-Foel, opposite Carnarvon. Here the drift rests upon a reddish clay belonging to the upper coal measures. About the middle of this section the drift is much contorted, and the boulders and pebbles stand vertically in the clay. The well-known foreign boulders appear to be almost entirely absent from this section, but boulders of a felsitic igneous rock are abundant.

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* Q.J.G.S., vol. lii., p. 630.

Near the Landing Stage the following beds were measured: —

Clay with small boulders..	6 feet
Gravel and coarse sand	30 ,,
Clay with boulders 1ft. in diameter ...	6 ,,
Red clay (coal measures undisturbed)...	10 ,,

The surface of the ground at the top of this section slopes slightly inland.

At the other end of the Menai Straits drift is exposed for about two miles between Beaumaris and Penmon. The "Mount," close to the town of Beaumaris, is a hill of boulder clay 40 or 50 feet thick. The boulders are chiefly limestone, many of which are striated. The "Mount" slopes inland like the drift at Tal-y-Foel already mentioned. In both instances this no doubt indicates that the sections have been weathered past their highest point, a fact which suggests that quite recently the drift must have covered much ground that is now under the water of the Straits. At the back of the "Mount," to the north, we find a series of mounds of drift following each other in the direction of the Vale of Llanfaes.

Between Friars and Lleiniog we find the contorted gravels mentioned by Professor Ramsay and others. The upper portion of the whole section consists of a reddish, unstratified clay, comparatively free from boulders. Below this clay come the gravels and coarse sand, and some intercalated clay, all being usually stratified, greatly contorted and much consolidated. A pillar of this hard drift, measuring about 25 yards around the base. and about 25 or 30 feet high, has been left standing for many years boldly facing the storms of the Straits. The lower portions of this section are full of boulders of limestone, of all sizes up to a giant measuring 15 x 12 x 10 feet, many of them being beautifully polished, grooved and striated.

Granite boulders of all sizes, up to one measuring 23 x 14 x 11 inches, are conspicuous. Boulders of felsites are also common. In places layers of boulders of coal a few inches in diameter can be seen.

In one place in this section the following beds were measured:—

Reddish clay with few boulders ...	6	feet
Gravel	$2\frac{1}{2}$	,,
Clay with boulders	4	,,
Fine gravel and coarse sand with fragments of shells	2	,,

In another place the measurements were:—

Reddish clay with few boulders ...	12	feet
Clay with boulders and gravel... ...	6	,,
Fine gravel and coarse sand with partings of clay	6	,,

Between Lleiniog and Penmon low banks of drift, similar in character to that already described, and containing the same erratics, are exposed, especially opposite the Deer Park.

Drift is next seen at Llanddona, on the east side of Red Wharf Bay. Here, banked against the shore, is a deposit of clay, sand and gravel about 45 or 50 feet thick. In places the upper portion consists of a reddish clay similar to that near Lleiniog; but in other places the surface is more sandy and shows distinct traces of stratification. In this section the gravel and coarse sand have consolidated into quite a hard rock. The cementing material here and at Lleiniog is chiefly carbonate of lime. Boulders of common and magnesian limestone, many well striated, are abundant, and granites and other foreign rocks can easily be found. In one place fragments of shells greatly decayed were observed.

Indications of the presence of drift are found all round Red Wharf Bay, and at Benllech, in a road cutting leading to the shore, a section of the hard boulder clay, known in Anglesey as "sentur," resting on a scratched surface of limestone, can be seen. Some drift is found near Dulas, but I am not aware of any exposures along the north coast.

Drift is next exposed on both sides of the channel dividing Anglesey from Holyhead Island. This appears to be of the "till" or "sentur" type, as can be seen in good sections along the coast between the Valley and Llanfachreth, and on the other side opposite Penrhos.

On the south-west coast drift of the "sentur" type is exposed at Llangwyfan Bay. The old church here stands on an island of drift, and its very position demonstrates that there has been here much erosion in recent times, and the tradition is that the land reached far into the sea in times gone by.

As mentioned already, inland exposures are not common, but gravel-pits have been opened in one or two places along the Menai Straits at heights of about 100 feet above the sea: the best known, and the only extensive one, being that on the main road near Menai Bridge. Some years back the following section was exposed here:—

Soil about	1 foot
Fine earthy gravel apparently dipping gently to the north-east	9 feet
A line of boulders from 6 to 12 inches in diameter, apparently sloping slightly to the south-west	1 foot
An intensely contorted bed of earthy gravel containing a few small boulders, about	10 feet
Another bed of earthy gravel containing many large boulders of Anglesey schists, about	8 ,,
Till or "sentur" depth unknown.	

This pit is well known for its pebbles of soft shale containing graptolites of Arenig Age.* I picked up a pebble containing the cast of a trilobite which my colleague, Professor Ainsworth Davies, identifies as *Æglina Binodosa*, Salt., another Arenig fossil. These pebbles of soft shale, which appear to have been lifted from the bottom of the Straits,* can be traced in a S.W. to W. direction for about three or four miles, to a gravel pit at Llwynon, about half a mile from the Straits, opposite Plas Newydd. Sparingly they are also found in the small gravel pits at Tyddyn Fadog and Hologwyn, about half a mile more inland.

Shallow pits are often observed in the superficial gravels of the Island. Most of the pebbles and boulders are angular or sub-angular, but an occasional well-rounded stone can be met with. The only gravel composed of well-rounded pebbles that I have seen is at Trefignath, near Holyhead, and here also is the only deposit of true sand that I have observed any distance from the coast.

I am not aware of any openings giving sections of clay that can in any way be compared with the tough, stoneless clay so often met with in Cheshire, and the fact that a brick-yard is practically unknown in the drift of the island is, I think, a good proof of its absence.

Undoubtedly the typical drift of Anglesey is the intensely hard, stony clay locally known as "sentur," and, naturally enough, excavations in it are not common. It can, however, be observed in many of the railway and road cuttings of the island; but it is difficult to get opportunities to study it in the valleys, where, no doubt, it is very thick. It is interesting to know something about the surface deposits in one of the valleys, viz., Gors Ddygau, or Malltraeth Marsh. This valley runs practically from Red Wharf Bay to Malltraeth, and cuts the island in two.

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* Geol. Mag., Vol. v. (1898), p. 561.

From Malltraeth to Ceint the valley is wide, very flat, and very little above sea-level. The three miles between Ceint and Red Wharf Bay is narrower, and filled with clay, coarse sand and gravels, as can be seen near Pentraeth, where the surface is about 50 or 60 feet above sea-level.

The Rev. Evan Jones, who is at present boring for coal in this valley, has kindly supplied me with the following account of the beds cut through before reaching the coal measures:—

FFERAM FAWR.

Sand with modern shells	36	feet
Blue clay	18	,,
Gravel	3	,,
Red stiff clay	24½	,,
China rock (boulder)	½	,,
Reddish sand	12	,,
	94	feet

A boring at Paradwys passed through 84 feet of sand and clay before reaching the coal measures, and at Malltraeth about 80 feet of sand and clay were cut through. On the east side of the valley 33 feet of clay, sand and gravel were passed through before reaching the Permian Sandstone, and at Berw 27 feet.

It is difficult to say what amount of the loose material in this valley can be classified as glacial drift; but one fact is clear, viz., that the bottom of the valley is 60 feet or more below sea-level. Other valleys, such as those of the Rivers Alaw and Braint, reach almost from sea to sea, and are, as already stated, full of drift. Indeed, it is clear that the bottoms of these valleys can not be much, if any, above sea-level.

GLACIATION AND STRIATION.—Nothing is more characteristic of the surface of Anglesey than the remarkable

difference between the appearance of the rocks when observed from the north-east as compared with their appearance when observed from the south-west. From the north-east the rocks appear smooth and flowing; from the south-west, on the other hand, they appear quite rough and craggy. It would be idle to mention examples of this feature, as it is so conspicuous in every district of the island. Grooves and striæ can be observed in many places, especially on the limestones and sandstones. Grooves and furrows can be often seen on the schists, but striæ hardly ever.

The prevailing direction of the striæ and furrows is north-east and south-west; according to Professor Ramsay, 35 degrees west of south. I have only found one example agreeing exactly with this direction, viz., on the yellow sandstone at Penrhoslligwy.

Boulders and their Distribution.—Boulders of all sizes, up to those weighing 30 or 40 tons, have been scattered broadcast over the Island. The surface at one time must have been absolutely paved with them. Generation after generation of farmers have been clearing them away, still they are legion. Two points regarding the distribution of these boulders should be noted:—

1. Boulders of any typical rock known in place can be traced to the south-west for four or five miles. Beyond this distance they become fewer and fewer. This is illustrated by the green schists containing epidote found near the Anglesey Monument; the quartz knobs found in various places; the yellow sandstone containing plant remains near the foot of the Tubular Bridge; and especially the black diorite near Llandyfrydog.

2. Boulders that can be examined in their natural position have been arranged with their long axes pointing generally to the south-west. A train of boulders, so arranged about 150 yards broad and nearly half a mile

long, can be observed along the border hedge between the two farms Llwynon and Tyddyn Fadog, near Llanfair P.G.

It should be noticed that we have evidence along the Menai Straits of the movement of boulders somewhat more to the west than usual in other parts of the Island. The yellow sandstone at the foot of the Tubular Bridge just mentioned is one example of this latter movement. The grit at Garth Ferry, mentioned by Mr. Greenly as having been lifted to the top of the hill at Llandegfan, has been carried almost due west.* The pebbles of shale containing graptolites found near Menai Bridge give examples of both uplift of boulders and movement almost due west.

This movement of boulders almost due west is probably the result of the Northern and Welsh ice-sheets shouldering each other along the line of the Menai Straits.

ERRATIC BOULDERS.—For some years I have been trying to identify some of the boulders collected in Anglesey. In making a collection of about 300 samples, notice was taken of every rock of which the local origin was not certain. The sections were searched from top to bottom, and the small boulders noted equally with the large ones.

Two points appear quite clear from this collection:—

1. The well-known granites that distinguish the Northern Drift are much more common in the eastern parts of the island than elsewhere, but specimens can be found sparingly in all parts.

2. Along the Menai Straits boulders of felsitic rocks are found abundantly; but they get fewer and fewer as one proceeds inland, and disappear altogether at a distance of between two and three miles from the Straits. Some of these boulders are very large. One measuring 9 x 5 x 5 feet lies near the Cromlech opposite Plas Newydd, and

* Brit. Assoc., 1898;

another measuring fully 8 x 5 x 4 feet lies near a spring at Hologwyn, Llanddaniel. The latter, Mr. Greenly informs me, is identical with the felsites of Snowdon. Mr. Greenly has also found several other large boulders of the same type near Llanddaniel.

A number of the most characteristic specimens in my collection were taken to London for comparison with the rocks in Jermyn Street Museum, and in order to clear up some doubtful points several specimens were afterwards sliced. Specimens from Lleiniog, Cemaes, Holyhead, and Llanddaniel were found to correspond with the Reibekite rock of Ailsa Craig. Various specimens were found to correspond with the following rocks:—the microgranite of Wastwater, the granophyre of Buttermere—two of the slides, one of them that of a specimen from the section at Tal-y-Foel opposite Carnarvon, correspond with the official slides of this rock—various granites from Dumfries, Kirkcudbright, and the well-known granite of Eskdale. Specimens were also matched with the porphyritic lava of Westmoreland, and the lamprophyre and the rhyolite of Cumberland. Chalk flints are plentiful all over the island.

In order to compare with the boulders found in the drift along the Menai Straits, and supposed to be of Welsh origin, specimens were collected in the area between Bethesda and Penmaenmawr. A boulder from the drift above the limestone in the Gromlech Quarry, Plas Newydd, was found to agree in every respect, both in hand specimens and under the microscope, with the "mica-bearing granophyre with porphyritic zoned felspars" of Gyrn, near Bethesda. A boulder of diabase from Hologwyn, Llanddaniel, similarly agreed with the ophitic diabase from near Llyn Anafon, above Aber, and a specimen from Beaumaris agreed with a specimen from the Drosgl.

Two other specimens must be noticed, one of porphyrite from Penrhoslligwy, that compares very well with the hand specimen and the slide of the mica porphyrite of Llwydmor, above Aber. The latter, however, is "slightly more basic than the boulder, which contains less mica, but they might well be from the same mass." If this be true, it is the only example of a Carnarvonshire rock having travelled far into Anglesey hitherto found. A specimen of granophyre boulder found in the Gromlech Quarry, Plas Newydd, compares very well with the survey rock specimen and slide from Clynnog Fawr, which is about 10 miles to the south-west of Carnarvon. If this identification be correct, this is the only example of movement from the south-west; but probably the rock can be found in place in Carnarvonshire much more to the east than Clynnog.

It is now, I believe, fairly clear that we have samples of Carnarvonshire rocks plentifully in the drift for at least a few miles into Anglesey.

One cannot avoid the question of the bearing of the drift phenomena as observed in Anglesey upon the theories regarding the Glacial Period, especially as we are within sight of Moel Tryfan, a place mentioned by almost every writer on this question.

To my mind the uniform *Moutonée* appearance of the rocks to the north-east, the distribution of the boulders to the south-west, and their orientation, and the general direction of the furrows, grooves and striæ, strongly support the theory of land ice moving in a south-west direction. Some argue strongly that the Moel Tryfan sand and shells were deposited in a sea. If so, at that time I presume Anglesey must have been under more than 1,000 feet of water; but the island itself, I think, lends no support whatever to this view. I know of no deposit that can be classified as marine drift in Anglesey.

As pointed out, all round the island we find indications of drift which is sometimes very thick. This fact appears to suggest that the rocky edge of the present island has not been far removed from the position it held when invaded by the ice. The question as to when Anglesey became an island is more obscure; but it is, I think, clear that the rivers of Carnarvonshire that now enter the Menai Straits have been factors working from very early periods in the direction of cutting off Anglesey from the mainland. The rivers Conway, Aber, and Ogwen, and other smaller streams, account for a large volume of water, which might account for the original breaking of the connexion between Great Orme's Head and Penmon, and the River Seiont and others might account for the opening at Aber Menai. This would have left a narrow neck of low land, composed chiefly of various soft rocks, that would be eroded from both sides until the last connexion was cut through in the neighbourhood of the bridges, where the channel is to-day narrow, very shallow, and studded with rocks. Professor Ramsay argued that this last link was cut through by the ice of the Glacial Period.* We have clear evidence of the excavating power of the ice in the lifting of the grits and shales from the Straits to the land 100 or 200 feet above, which has been already referred to. There is, therefore, nothing improbable in Professor Ramsay's suggestion; but no one, I presume, would now contend, as he did, that the north-east and south-west valleys of Anglesey are entirely due to ice work.

However, we are not without some evidence that Anglesey was not only an island but many islands, even at the approach of the Glacial Period, and that its very existence as a habitable place is due to the work of the ice of the Glacial Period, which "filled its valleys and brought low its hills and mountains."

* Q.J.G.S., Vol. xxxii. (1876).

It seems clear that ice from Carnarvonshire in some way invaded Anglesey; but this invasion does not appear, from the evidence left us, to have been direct. The ice coming down in the direction of Puffin Island and Great Orme's Head appears to have been dragged along by the ice moving in a south-west direction, as suggested by Professor Kendal.* This idea seems to explain all the facts regarding the presence of Carnarvonshire boulders in Anglesey.

We are not without evidence in favour of the view that the Glacial Period left the Menai Straits as a large lake, both ends being blocked by great mounds of drift, the remains of which have been already described. The surface of Anglesey was also clearly left studded with lakes. Most of them have now disappeared; but their positions are still indicated by the shallow deposits of coarse sand and gravel seen in many places.

I must be allowed to thank the authorities of Jermyn Street Museum for their kindness in helping me to compare the boulders from Anglesey with the survey specimens. Mr. John Rhodes, especially, gave me great assistance and valuable hints.

* Man and the Glacial Period, p. 145.

NOTES ON SOME SPECIMENS OF LANCASHIRE BOULDER CLAY.

By T. Mellard Reade, F.G.S.

General Observations.

As showing the remarkable persistence and homogeneity of the Lancashire Low-level Marine Boulder Clay, the specimen A is worth recording. It is one more of numerous examples I have had the pleasure of bringing before the Society in which marine organisms in the form of foraminifera are present in abundance, pointing strongly to the probability of the whole of this Boulder Clay having been laid down in marine waters under fairly quiet conditions.

It is in the finer qualities of the clay that the foraminifera occur in the greatest proportion.

Specimens B are from a coarser and more heterogeneous deposit, though the inorganic characteristics are in certain respects similar to A, but ash rocks are more numerous.

Many granite and other boulders, some of them large, have been taken out of this clay, where graves have been dug. Some of these have been preserved by the Vicar, the Rev. C. H. James.

A very few foraminifera were present in one of the specimens. From the absence of fine deposit this barrenness was not unexpected.

Description of Specimens.

Specimen A.

Boulder Clay.—Alder Road, Eaton Road, Knotty Ash, near Liverpool, from sewer heading, about 27 feet below surface and 70 to 80 feet above ordnance datum; collected by Mr. W. M. Reade, 1st October, 1904.

This specimen was typical Low-level Marine Boulder Clay, of fine texture and of a chocolate colour; it reminded me of the clay in Cook's Lane, Great Crosby, in which the Gypsum boulder was found.

The weight of the clay, as given by Mr. Wright, who kindly examined it for foraminifera, was 76·8 oz. troy. Of this, after washing, there remained 8·7 oz. coarse gravel and pebbles, and of fine sand 26·2 oz.

The coarse material consisted of the Lake District rocks, granite, grit, &c., usually present in the Low-level Boulder Clay of Lancashire, together with a considerable proportion of Triassic sandstone. Some of the pebbles of Silurian grit were well water-worn, and facetted and striated on several planes. Fragments of marine shells were plentiful in a minute form, as well as determinable specimens of *Cardium* and *Turritella*.

The characteristics of the clay and its organic and inorganic contents were quite typical of the extensive mantle of Boulder Clay which forms the South-west Lancashire Plain.

The excavations show that the clay lies upon Triassic Sandstone, the specimen coming from near the base naturally included more of this rock than is normally present.

Foraminifera were plentiful. Mr. Wright obtained 77 specimens of *Nonionina depressula*, 61 of *Cassidulina crassa*, 32 of *Bolivina plicata*, 48 *Globigerina bulloides*,

and 26 of *Orbulina universa.* The other species were in lesser numbers, the total being estimated at 550 specimens.

The following is a complete list of the species identified:—

Miliolina subrotunda, Montag., rare.
Textularia globulosa, Ehr., rare.
Verneuilina spinulosa, Rss., rare.
Bulimina pupoides, d'Orb., very rare.
,, *elegantissima,* d'Orb., one specimen.
Bolivina plicata, d'Orb., common.
,, *dilatata,* Rss., frequent.
Cassidulina lævigata, d'Orb., one specimen.
,, *crassa,* d'Orb., very common.
Lagena lævis, Montag., one specimen.
,, var. *clavata,* d'Orb., one specimen.
,, *lineata,* Will., one specimen
,, *marginata,* W. & B., very rare.
,, *lucida,* Will., one specimen.
,, *Orbignyana,* Seg., one specimen.
Uvigerina angulosa, Will., very rare.
Globigerina bulloides, d'Orb., very common.
,, *cretacea,* d'Orb., frequent.
,, *sacculifera,* Brady, one specimen.
Orbulina universa, d'Orb., common.
Discorbina globularis, d'Orb., one specimen.
,, *rosacea,* d'Orb., very rare.
,, *obtusa,* d'Orb., rare.
Truncatulina lobatula, W. & J., very rare.
Pulvinulina Karsteni, Rss., rare.
Nonionina depressula, W. & J., very common.
Polystomella striato-punctata, F. & M., rare.

The foraminifera at this locality are typical of Boulder Clay deposits; they are very small in size, the prevailing forms being *Cassidulina crassa, Bolivina plicata,*

Globigerina bulloides, *Orbulina universa*, and *Nonionina depressula*. *Globigerina sacculifera* was the most interesting species met with; only one specimen was found, and this was not a typical example— this form has not hitherto been recorded from Boulder Clay.

SPECIMENS B.

BOULDER CLAY.—Haigh Churchyard, near Wigan, Lancashire, collected by Rev. F. F. Grensted, April 5th, 1904.

Level about 500 feet above sea. Contained Eskdale granite (typical), felspathic ash of dark green colour, one small pebble well glaciated. The ash was decomposed at the surface, and so white as to look like limestone.

The surfaces of the pebbles not glaciated are rough, minute clastic bits or crystals projecting, due to the surface-decomposition of the matrix. Fine-grained granite, such as is ordinarily found in Lancashire Boulder Clay, occurs, perhaps derived from a granite vein.

Except a nodule from the coal measures, the rocks were from the Lake District. The Boulder Clay is of a very mixed character, and is of a bluish-grey colour at 8 feet deep.

A microscopic examination by Mr. Wright disclosed a very few foraminifera in the upper part of the clay.

The following is a description of the sand, &c., retained in the sieve after washing:—

No. 1.—Three feet deep. Weight of sample, 7·1 oz. troy; after washing—fine, 2·6 oz.; coarse, ·3 oz.

The coarse material, small in quantity, consisted of small fragments of the rocks already described. The fine material was mostly quartzose sand, with some highly-polished grains.

The following foraminifera were present:—
Miliolina subrotunda, Montag., one specimen.
Bolivina dilatata, Rss., one specimen.
Nonionina asterizans, F. & M., three specimens.
„ *depressula*, W. & J., three specimens.
Polystomella striato-punctata, F. & M., one specimen.

No. 2.—Seven feet deep. Weight of sample, 7·8 oz. after washing; fine, 2 oz.; coarse ·14 oz. Similar to No. 1, but larger fragments. The sand was quartzose, like No. 1, but finer in the grain—yielded only one *foram*, viz.:—*Nonionina asterizans*, F. & M.

No. 3.—Eight feet deep. Weight of sample, 11·3 oz.; after washing—fine, 3 oz.; coarse, 2·2 oz.

The coarse material similar in character to preceding, but in greater quantity.

The pebbles are more angular, the finer material more rounded. The fine stuff does not hold so much clear quartz, and extraneous material is mixed with it, which gives the sand a darker shade; looks as if the sands had been largely derived from Carboniferous Yellow Sandstone.

No foraminifera were found.

NOTES ON A RECENTLY EXPLORED FAULT-FISSURE ON INGLEBOROUGH.

By Harold Brodrick, M.A.

Ingleborough Hill, in North-west Yorkshire, near the junction of that county with Lancashire and Westmoreland, is remarkable for the number of what are locally known as pot-holes which are to be found on it. Ingleborough consists of a large plateau of Carboniferous Limestone, which rests unconformably on the Silurian grits; the central portion of this plateau is capped by a cone of Yoredale rocks, while the actual summit of the hill is composed of Millstone Grit. The top of the hill is 2,373 feet above o.d., while the plateau ranges in height from 1,200 feet to 1,400 feet, so that there is a considerable collecting ground for streams above the limestone; the streams which run down the Yoredales, on reaching the limestones, at once sink to reappear at the junction of the limestones with the Silurians some 400 feet below their point of disappearance. In some cases, these streams slip away through innumerable small apertures, so that it is difficult to say where exactly they pass underground; in other cases they fall down the vertical shafts to which the name pot-hole has been given. At present there are known to be on Ingleborough seven of these pots of a greater depth than 200 feet, eight more of a greater depth than 100 feet, and at least 15 of a lesser depth. In a great number of cases there are streams falling into these pots, but many of them are dry; there is a considerable deposit of glacial drift on the limestone plateau, and one,

at least, of the pots has been proved to be pre-glacial,* so that the absence of a stream at present does not prove that the pot was not formed pre-glacially by a stream which has been diverted by drift.

Until recently, it was generally considered that all these pot-holes owed their origin to water action, although it was thought by many that some other contributing cause was needed to explain the great depth and straightness of some of them. Rift Pot, the subject of this paper, was fully explored by members of the Yorkshire Ramblers' Club in August, 1904; it is not marked in the Survey, but is situated on a portion of the hill called the Allotment, at a point about a mile and a half S.E. of the summit at a level of 1,340 feet above o.d. The chief portions of the pot consist of a fissure, ranging in width from 5 to 15 feet with platforms of jammed stones at intervals. At the moor level the fissure is 60 feet long and 7 feet 6 inches wide in the middle, at the northern end it thins into a crack a few inches wide, while to the south it widens to about 20 feet. At 25 feet from the surface the fissure narrows in the centre to about 3 feet, from this point it widens, until the floor of the main chamber is reached at a depth of 114 feet below the surface; this main chamber is about 130 feet long and 25 feet broad, with its greatest length north and south; its height is about 50 feet. The floor of this chamber seems to be entirely composed of jammed stones, so that it is possible that there is a further chamber below. At the south end of this chamber the walls come to within 4 feet of each other. Below this point there is a drop of about 100 feet between vertical walls a few feet apart; supported between these walls are a series of platforms formed of jammed stones. The walls at this

* Proceedings of the Yorkshire Geological and Polytechnic Society, Vol, xv., Part II., p. 281.

part are in a very unstable condition and great care was needed in the exploration. The lowest of these jammed platforms leads into a water-worn shaft, at a point about 220 feet below the surface; this shaft is of unknown height, but certainly reaches upwards to within a comparatively short distance below the moor level. The lower portion of this shaft presents the usual characteristic water groovings which are to be found in all the pots which have streams falling into them at present; there is a small quantity of water flowing down the walls of this shaft, forming a pool at the bottom leading into a short water-worn passage. This pool is at a depth of 320 feet below the moor. This shaft may be at once dismissed, as its formation is, at any rate in some measure, attributable to water action.

At the northern end of the fissure, near the moor level, the east wall is slickensided. The slickensides at this place do not cover much of the rock, the greater portion having been probably removed by atmospheric influences; in the main chamber, however, the east wall is slickensided over an area 50 feet in length and at least 20 feet in height. At the surface the slickensides occur along successive master joints, while those in the main chamber occur along another master joint at a horizontal distance of about 15 feet, thus proving that the faulting took place along several parallel lines. These slickensides are horizontal, showing that the fault was one of horizontal displacement, and, as a careful examination shows that the beds of limestone on either side of the upper part of the pot correspond, at any rate to within a few inches, it is clear that no vertical movement accompanied the faulting. No slickensides are to be seen on any of the west walls of the fissure.

The slickensides near the surface are coated with clear crystals of calcite, which can be pulled off in slabs several

inches in area. The slickensides under these crystals are very clearly marked, not having been acted upon by the atmosphere; the largest crystal I met with had a diameter of $\frac{5}{8}$in. These crystals have obviously been formed by infiltration along the line of the open joint.

The narrowest, or northern, end of the fissure, down to a level of about 20 feet from the surface, is filled in with angular fragments of limestone, ranging in diameter from half an inch up to a foot or more; these fragments have been almost entirely coated with clear crystals of calcite, which are now etched and polished as if by water containing fine powder running over them. The limestone fragments are grey in colour, and of a darker shade than most of the limestone of the district, being probably formed from a bed of the "marble" of the district, several beds of which are to found in various pot-holes near. On examining a thin slice of one of these fragments under the microscope, it is found to be made up of still smaller fragments of limestone cemented together by veins of calcite. The limestone itself is exceedingly fossiliferous, containing, in the thin section, polyzoa, brachiopoda (one with spiral arm), encrinite stems, corals and foraminifera in abundance. In the limestone there also occur a few small pieces of quartz; these are angular and splintery, and vary in size from ·1mm. to ·25mm. At the northern end of the main chamber is a bank of heavy clay some 20 feet high; this clay is a very dark blue-grey when wet, but when dry is much lighter in shade, it consists almost entirely of an exceedingly fine impalpable powder, and is almost certainly the residue left after the solution of the limestone. If this clay is washed for a long time, a small residue is left of quartz grains similar to those found in the limestone. It has been suggested that this clay is a glacial deposit which has been washed down. This is improbable, as the

glacial deposits on the surface seem to be entirely composed of sand and gravel with no admixture of clay; it is more probable that it is formed by solution along the line of the fault.

From the exploration of this pot, it has been conclusively proved that it owes its formation to a fault of horizontal displacement, a type of fault which naturally gives, at the best, only slight indications on the surface, and, from a consideration of the shape and general characteristics of the majority of the pot-holes, it is probable that many, if not all, of them owe their origin to a similar cause, although up to the present slickensides have not been found in any other case.

NOTE.—For a plan, section, and fuller description of Rift Pot see "The Yorkshire Ramblers' Club Journal," Vol. ii., No. 6.

SANDS AND SEDIMENTS.

By

T. Mellard Reade, F.R.I.B.A., F.G.S.,

and

Philip Holland, F.I.C.

Part II.

Geologic Sediments of Marine, Estuarine, or Fresh Water Origin.

In the examination of recent deposits, whether fluviatile or marine, we are necessarily confined to practically surface examples.

This was the case with those samples experimented with in Part I. of this paper.

The finer deposits, also, being generally sub-aqueous, are more difficult to collect. Although there are very fine-textured sediments distributed amongst those of a generally coarser nature allied to "muds," they are, as will be seen on reference to Table I., Part I., present in but small quantities.

With the object of getting larger quantities of fine sediments to deal with by subsidence and analysis, we decided to collect specimens from some of the later geological formations. The vertical range of the sedimentary conditions was thus also varied and enlarged.

The majority of the specimens, it will be seen, on reference to the descriptions and to Table II., were collected in the Isle of Wight, and range from the Wealden to the Pleistocene. In this classic ground of

geological research exceptionally interesting beds are met with. As pointed out by Ramsay, Bonney, and other geologists, there occur here deltas of several ages overlapping and superposed upon one another, and proving the recurrence of somewhat similar conditions at successive and distant geological periods. Marine, estuarine and fluviatile beds interchange frequently, especially in the Tertiaries.* Sometimes fresh-water shells are intermingled with a preponderatingly marine fauna, and *vice versa*, so that the conditions under which the deposits accumulated admit of no dispute.

The clays of the London Basin, of which we have tabulated three examples, are deposits geologically analogous to the Isle of Wight tertiaries. The Oxford clay collected by Mr. Laurence Grensted is the only sample outside the areas of the Isle of Wight and the London Basin.†

We have thought it clearer for our purposes to make a distinction between sediments now being carried along by rain or rivers, the product of current subaerial waste, and those which, having come to a final rest, go to form geological beds and formations. We shall therefore call these latter "Geologic Sediments."

Scope and Meaning of the Experiments.

The experiments have been conducted on the lines of those described in Part I., and the results tabulated on the same system. A comparison of Table II. with Table I., Part I., will show that the finer particles which are held in suspension in a column of water 15 inches high are in greater bulk in the "Geologic Sediments" than in the

* See "Fragmental Rocks as records of the Past," by Professor Bonney, Proc. of L'pool Geol. Soc., Pt. 2, Vol. IX., 1901—1902.

† The Sediments of Bala Lake to be considered later on are not "Geologic sediments" but Recent Deposits.

riverine muds experimented on in Part I. This is what one would *a priori* expect. The suspended matter, speaking broadly, is of the same character in both cases, and while some is left mixed with the riverine sands, the bulk of the finer suspended matter is carried seawards, to subside in quiet waters or deep oceans. This fine suspended matter is of much interest and of the greatest geological value.

In Part I. we have already spoken of the tendency of carbonate of lime to concentration in the finer precipitated matters, and the probability of detritus of limestone or chalk being carried far out to sea before finally sinking on the ocean floor. The analysis of the deposit from one of the brine pans of the Anderton Salt Works, Northwich, given in detailed experiments, tends to support this view.

That finely divided clayey material can be carried out to sea, but in such small quantities that it is undetectable by the eye or by ordinary methods, has long been the view of one of us. Our experiments have deepened this conviction.*

The influences that hasten or retard precipitation are somewhat obscure; all clays do not behave alike. The factors of these variations are probably many—specific gravity, size and shape of particles, temperature, and those more refined physico-chemical causes that come into play with the introduction of salts into the waters of suspension.

The Causes of the Colours of the Sea.

In this connection it will be well to call attention to Professor Tyndall's investigations. In a communication to "Nature" (vol. IV., p. 203) he shows that the variations in the colours of the sea are largely due to suspended

* See "Denudation of the two Americas" republished in the "Evolution of Earth Structure," Longmans Green & Co., pp. 272—273.

particles present. "The indigo to which I have already referred is, I believe, to be ascribed in part to the suspended matter, which is never absent, even in the purest natural waters, and in part to the slight reflection of the light from the limiting surfaces of strata of different densities." After describing an experiment at sea by sinking a white plate, which at all depths appeared more or less green, Tyndall goes on to say—"If the plate, instead of being a large coherent mass, were ground to a powder sufficiently fine, and in this condition diffused through the clear sea water, it would send green to the eye. In fact the suspended particles which the home examination revealed in green sea water act in all essential particulars like the plate." Particles of chalk diffused through the sea water would seemingly fulfil the conditions stated by Tyndall.*

The detailed experiments on flocculation are of value, as showing the curious influences finely suspended matter in sea water may be subject to. Temperature, for instance, is one of the governing causes, and it is well known from oceanic temperature soundings that there is usually a stratification of water of different temperatures met with, varying with the different currents and ocean localities. Again the whole bottom water of the deeper oceans is ice-cold, though the water may be as high as 80 degrees F. or more at the surface. It may well be that sea-water at 80 degrees F. may initiate flocculation and precipitate matter that might come to a stand, or its subsidence be checked in the deeper and colder areas.

The distribution of sediment over the ocean floors is governed by many conditions. We believe the deposits to

* Suspended clay particles to the amount of ·0052 grains per litre have been found in Mid-Atlantic water and ·0066 in Mediterranean water and it is suggested in the *Challenger* report that Diatoms and Radiolarians have obtained the silex from these suspended clay particles—see Annals of British Geology, 1891, p. 16.

be much more varied in composition and distribution than was inferred in the earlier days of the *Challenger* expedition. In the extract from a letter to Hon. M. Bowers, U.S. Fish Commissioner, dated Lima, November 28th, 1904,* Professor Alexander Agassiz, speaking of the *Albatross* expedition to the Eastern Pacific, says—" The number of Diatoms found in this tropical region is most interesting. They have usually been considered as characteristic of more temperate and colder regions. On several occasions the surface waters were greatly discoloured by their presence and the extent of their influence on bottom deposits is shown by the discovery of a number of localities where the bottom samples at depths from 1,490 to 2,845 fathoms in the track of the great Peruvian current formed a true infusorial earth."

Again, between the Galapagos and Callao vegetable matter was not uncommon in the trawl, while north of the Galapagos such matter was found at nearly all the stations. In the track of the Peruvian current, " at not too great distances from the coast we invariably brought, even from very considerable depths, sticks and twigs and fragments of vegetable matter." Between the Galapagos and the Isthmus of Panama the floor of the sea was proved in a previous expedition to be largely fine mud, with much vegetable remains.† " Off Mariato Point the *Albatross* made two hauls in the vicinity of the stations where in 1891 she found 'modern green sand.' It was interesting to find the green sand again, as the previous specimens were lost in transit to Washington. The temperature soundings were equally interesting, a difference of 12 degrees between the surface and 50 fathoms occurring at one station, while at 600 fathoms it had dropped from 71·7 degrees at the surface to 40·7 degrees, the bottom

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* American Journal of Science, Feb., 1905, p. 145.

† See " Evolution of Earth Structure " pp. 93—94.

temperature at 2,005 fathoms being 36·4 degrees. In another locality the range of temperatures between 30 and 150 fathoms was as great as 21 degrees."

Our experiments show that temperature is one of the conditioning factors in precipitation of fine matter suspended in sea water. May it not be that the great spread of fine muddy bottom off the coast of Central America and part of South America is due—combined with currents known to exist—to the high surface temperatures and sudden lowering of temperature at moderate depths until finally ice-cold water is reached in the bottom soundings? Mud that became precipitated at a high temperature falling into a colder stratum of water would have its downward course arrested, and at all events it would be held in suspension longer, and enable currents to disperse it and spread it over a larger area of sea bottom.

Agassiz's description of these Eastern Pacific soundings and dredgings brings strongly to mind the Isle of Wight Cretaceous and Tertiary muds which have been the subject of our experiments, though doubtless these latter are from lesser depths.

In applying laboratory experiments to geological phenomena we are beset with the difficulty of ascertaining the effect of movements of the water, such as occur in nature, in preventing precipitation. We think the effect must be considerable, especially on those ultra-microscopic particles which have been proved to exist in oceanic water. Some of our precipitation experiments by sea water were made with a mixture of clay and fine chalk, from which it appeared—proved by frequent repetitions—that when the clay is down a good deal of chalk remains in suspension at the end of an hour's repose. Thus when all the clay is precipitated by the addition of sea water, there remains chalk still in suspension = 13·7 parts per

100,000 of water. Curiously also, when the chalk was halved in proportion to the clay this did not, as one might expect, halve the amount of the chalk which remained in suspension. A reference to the details of these co-precipitation experiments with clay and chalk will more fully explain these interesting results.

All our experiments point towards the greater permanence of suspended chalky matters in sea water over other minerals under the same conditions. There is, however, an unknown quantity as a factor to be considered, namely, the length of time it will take sea water to dissolve such chalky particles.

We may, however, legitimately infer that the solvent action of sea water is slow, considering the immense accumulations of distinguishable calcareous tests of foraminifera that occur on the ocean floor. These organisms, it is contended by many naturalists, in most cases lived at or near the surface, and when we consider their hollow form, liability to retain air and low specific gravity, their subsidence must have been slow.

In the abysmal depths represented by the red clay these tests are absent, due, it is thought, to the longer time they have been exposed to solvent influences and the greater solvent powers of the bottom water.

Application of the Experiments to the Explanation of Geological Phenomena.

There are some classes of natural phenomena that are best understood by direct appeal to nature, and this method has been used by geologists in the past with remarkable results; others, for their explanation, demand refined physical methods.

The variations in the deposition of sediment by rivers and on the sea bottoms and ocean floors has hitherto been

mostly looked upon as the result of varying specific gravities, size of particles, and strength and depth of currents.

The refined methods of a laboratory do not give the conditions met with in nature, but they enable us to isolate certain phenomena and study them separately.

An appeal to nature on the large scale is necessary at every stage of progress, and in our case that appeal must be to the facts of geology and oceanography, of river action and subaerial waste. The one thing absent in our refined experiments is that of motion in the water, and we can only reason on the probable difference such motion will have in influencing and preventing deposition.

The general character of the sediments dealt with in this paper is such that they are mostly known and spoken of as "clays," and as will be seen from the general description of the specimens, many of them are used for the manufacture of bricks and tiles of a common class. It will be noted on reference to the Table II. that the fine matter separated from the several specimens by 18 hours' suspension varies considerably from 19·09 in the Wealden to 1·19 in the Tertiary black clay, Alum Bay. The Wealden was undoubtedly laid down in deeper waters than the Tertiary clays.*

The variations that occur in the clays are just those that might be expected in an area subject to the fluctuating conditions of subaqueous deltas.

At one time floods of fresh water would bring down chalky and clayey detritus, and at another, under steady, quiet conditions, these materials would be sifted and

* The residual pleistocene clay in "Angular flint gravel of Chalk Downs" at Rew Down, yielded 19·86 showing that fine material does not necessarily indicate a deep-water deposition. It must be borne in mind however that as this residual clay is derived from the destruction of the chalk some of the finer particles may have been originally deep sea deposits.

differentiated depositions would result, such as occurred in some of our cylinder experiments. These depositions would also be influenced by the salinity or non-salinity of the water and stratification of water at different temperatures. In this way a small quantity of extremely fine material might become mixed with coarse material, or even stratified with it. In times of floods and storms the coarser material would be carried further out to sea and along the sea bed; in placid conditions the finer material might, subject to the influences we have been investigating, be precipitated even on the shores.

We feel, although the experiments have entailed much labour and study, that we are but on the threshold of discovery. That we may be pointing the way for others is our earnest wish.

Considering the complexity of the subject and the agencies involved, we have for simplicity's sake avoided as much as possible repetition, and we must ask fellow-students of nature to direct their attention to the experiments themselves, and not to confine themselves to our provisional interpretations.

If, however, time and opportunity be permitted us, we hope to carry the subject further in another communication.

GENERAL DESCRIPTION OF SPECIMENS.

Jurassic.

No. 1.—Oxford Clay, collected by Mr. Laurence Grensted, at Summertown, near Oxford.

This specimen weighed about 8 oz. It was light grey when dry, rich in carbonate of lime, and contained 1·86 per cent. of pyrites, some in grains easily seen on washing the clay with acid. There was also some as fine dust.

Bits of woody fibre with adherent pyrites were visible with the microscope. Grains of sand were few, and of small size. On suitable treatment of the clay with acids there remained a black residue which burned readily on platinum foil. This carbonaceous residue has been observed in other clays, and in slate rock.

CRETACEOUS.

No. 2.—Wealden Clay, from cliff E. of Brook Chine, Isle of Wight, collected by Mr. T. M. Reade.

This had a purple shade when fresh. It was in a partially dry state, and weighed over 8 oz.

No. 3.—Gault Clay in situ, *from Bierley Brick and Tile Works, 2 miles N.E. of Blackgang Chine, Isle of Wight, collected by Mr. Reade.*

A dark grey specimen, weighing about 9 oz., of quite fine texture. The 90-mesh sieve retained a few well rounded grains of quartz, with flakes of mica. The size of the largest grains of quartz was just over ¼ mm.

We are indebted to Mr. Joseph Wright, F.G.S., for an examination of the clay for foraminifera, and he kindly gives us this list.

FORAMINIFERA.

Spiroloculina papyracea, B. S. & B.
Miliolina venusta (Kar.)
Cornuspira cretacea, Rss.
Haplophragmium agglutinans (d'Orb.)
H. latidorsatum (Born.)
H. nanum, Br.
H. globigeriniforme (P. & J.)
H. æquale (Römer).
Ammodiscus incertus (d'Orb.)

A gordialis (J. & P.)
Spiroplecta complanata, Rss.
Textularia minuta, Berth.
Bulimina obtusa, d'Orb.
Gaudryina filiformis, Berth.
Nodosaria communis (d'Orb.)
Pleurostomella obtusa, Berth.
Globigerina cretacea, d'Orb.
Truncatulina lobatula (W. & J.)
Anomalina ammonoides, Rss.
Pulvinulina Micheliniana (d'Orb.)
Rotalia orbicularis, d'Orb.

The greater part of the Foraminifera are arenaceous forms, but the specimens are not in good preservation.

No. 4.—Slipped Gault, Cliff Farm brickfield, collected by Mr. Reade.

This was a grey plastic clay with iron stains on some of the fragments. Collected from face of the excavation in several places and mixed. There was rounded quartz on all the sieves, and mica was very noticeable on the 90-mesh, with some grains of red decomposed rock and fragments of plant fibres. The clay is named "slipped Gault" on the Geological Survey Map, as it is thought not to be *in situ*.

Tertiary.

No. 5.—A, B, C—Eocene Clays of the London Basin.

These comprised three specimens—A, B, and C. *Specimen A* was the highest in the series, a dark brown (when wet) homogeneous cohesive clay, quite free from stones or gravel. When received and dried at 120 degrees C. it gave 19·45 per cent. of moisture.

Specimen B underlies *A*, and is known to those engaged in the tunnelling as "blue marl." It is blue when fresh got, but soon becomes grey on the surface. The moisture when received was 31·52.

Specimens *A* and *B*, which weighed some 10 lbs. each when wet, were collected in December, 1904, at a point in the tunnel of the Charing Cross, Euston, and Hampstead Electric Railway, between Seymour Street and the East side of Tottenham Court Road.

We are indebted to Mr. O'Keeffe, the timekeeper at the Drummond Street shaft, for the specimens. We are told that the tunnel hereabouts is over 80 feet below the street level.

Specimen C was collected in December, but a week later, near Warren Street, on the West side of Tottenham Court Road.

B, the "blue marl," appears to occur in pockets of considerable size in the brown clay deposits, for we are informed that in the course of the tunnelling the cutting shield occasionally passes from brown clay through the marl and again into the clay. Septarian nodules are at times met with in this section of the railway. One recently found at the northern end of Seymour Street was estimated to weigh 2 cwt., and from its position appeared to be embedded in the upper brown clay.

C underlies *B*. It is a brown clay, but had internal bluish mottling. Both it and *A* are free from stones and gravel. It is spoken of by the workmen as Reading clay, because a similar clay outcrops at Reading, but whether it be geologically the same we cannot say. The moisture determined immediately on arrival of the clay at the laboratory was found to be 10·04 per cent. The specimen weighed 8½ lbs. This clay had over 9 per cent. less moisture than the upper brown specimen.

No. 6.—Clay from under Limestone Bed (A), Colwell Bay, Isle of Wight, collected by Mr. Reade.

Consisted largely of shell fragments loosely cemented by calcareous mud containing fine sand.

No. 7.—Clay bluish when wet (B^2.)

Crowded with shell débris, mostly oysters. Same locality as preceding. There are several small univalves and fragments of a shell of the genus *Nucula*. The oysters are very much bored by *Cliona*, and are overgrown with zoophytes—a marine deposit probably between tide marks. A partial analysis of these two deposits gave—

	A1.		B2.
Shell Carbonate	45·67	...	36·10
Sulphate of Lime	0·40	...	1·71
Phosphate of Lime	0·11	...	0·08
Ferruginous Clay, Sand, etc. ...	53·82	...	62·11
	100·00		100·00

MEM.—From the nature of this specimen it was not thought worth while to examine it for tabulation—it is, therefore, absent from the Table.

No. 8.—Purple Clay, Alum Bay, Isle of Wight, collected by Mr. Reade. Weight nearly 9¾ *oz.*

The strata here are nearly vertical, the specimen being taken from near the flank of the chalk. As there are considerable slips taking place from time to time, a little extraneous material may have got into the specimen.

When received a week or two after collection, it had a dull brick-red appearance, with internal grey portions in some of the lumps. It contained one or two black flints and just a few bits of flint the size of a pea. These were all removed. The smaller gravel was well mixed up before removal of what was to serve for analysis.

No. 9.—Black Clay, Alum Bay, Isle of Wight, collected by Mr. Reade.

North of preceding specimen. Coal-black grains were observed in the sand on the sieves, which burned when heated on platinum foil, but did not intumesce or inflame.

No. 10.—Clay from Dowty's Brick and Tile Works, Totland Bay, Isle of Wight, collected by Mr. Reade.

A grey clay.

PLEISTOCENE.

No. 11.—Clay in "Angular Flint Gravel of Chalk Downs," from Rew Down, Isle of Wight, collected by Mr. Reade.

A residual deposit.

No. 12.—Plateau Gravel; irregular Bed of Loam in Gravels, Blake Down, Isle of Wight, collected by Mr. Reade.

A reddish brown specimen. It held 11 flint pebbles, of which the longest measured an inch. The smaller measured from $\frac{1}{8}$ to $\frac{1}{4}$ in. They were removed before analysis.

No. 13.—Clay from Apse Heath brickfield, collected by Mr. Reade.

The bed from which this is taken is a brown clay, quite free from pebbles or gravel. It is known among the men as "the best brick clay." There are several beds of clay lying somewhat irregularly, and varying in character and quality.

No. 14.—Residual Clay from "Angular Gravel of Chalk Downs," Bonchurch Down, Isle of Wight, collected by Mr. Reade.

The specimen weighed nearly 10 oz., and was light brown in colour. It held one flint flake $\frac{3}{4}$ in. long, and six

rounded, very small pebbles of a much decomposed rock having a rusty fracture.

No. 15.—*Indurated Pleistocene Sand, showing columnar structure, Brook Chine, near Freshwater Bay, Isle of Wight, collected by Mr. Reade.*

It consisted of one fragment.

PRELIMINARY REMARKS ON THE SUSPENSION EXPERIMENTS WITH SEDIMENTS IN DISTILLED WATER.

Flocculation of Clay in Suspension.

When a cylinder of muddy water is set aside the bulk of the sand, with some clay, settles almost at once. The finer portion remains suspended for longer periods, whilst the finest leaves an opalescence visible for many months.

In some cylinders, after a month's rest, there was a distinct stratification of the finest deposit. In descending order there was at times a thin black layer—probably humic matter—succeeded by one of lighter shade, and this again by a brownish layer. The observation is not new, for Professor W. H. Brewer, formerly of the Geological Survey of California, records a similar experience in a paper read at the New Haven meeting in 1883, entitled "The Subsidence of Particles in Liquids."*

Brewer gives many experiments of his own on the flocculation of clay in water and on the causes which induce it to settle. Various salts are shown to be potent agents, as indeed was known through the investigations of other experimenters. "Sea water added to muddy water curdles or flocculates the clay, which immediately begins to fall, and in a comparatively short time the liquid

* National Academy of Sciences. Third Memoir, pages 165—175.

becomes clear." This precipitating action of sea water on mud, others, in common with Brewer, regard as a predisposing cause of mud bars in estuaries, and consider that chemical action, as well as mechanical processes, in part contributes to such depositions.

Heat and cold cause flocculation. Freezing a water but slightly opalescent from suspended clay coalesces ultra microscopic particles to larger aggregates easily seen in the ice. If water holding fine mud be frozen, the mud, says Brewer, "becomes largely disposed along lines of crystallisation in the ice, and if this be slowly thawed in the quiet, it falls and does not rise again." Thus extreme cold may be an important factor in sedimentation. "It is obvious that each and all these various facts have their geological significance, and phenomena immediately suggest themselves where they certainly or possibly play a part" (*loc. cit.*, p. 167.)

A few years ago one of us received from the late Mr. Thomas Higgin, of the Anderton Salt Works, Northwich, a parcel of extremely fine dark mud, which he, in the process of manufacturing a superior quality of salt, had separated from the brine of the wells.* Mr. Higgin found it to be of so fine a texture that it did not settle in the cold brine, but did so after heating the brine to 107 degrees F. and allowing it to cool. The annexed analysis proves this mud to consist largely of calcium carbonate, along with some fine sand and ferruginous clay:—

$CaCO_3$	77·05
$CaSO_4$	2·32
$NaCl$	3·24
Clay	10·29
Sand and Insoluble in Acid	7·10
	100·00

* This is the muddy impurity held in suspension referred to in note at foot of page 273, "Evolution of Earth Structure."

It would appear that chalk of fine texture is not readily flocculated by common salt. If the same be true of marine salts, the observation will support a theory that much of the suspended chalk brought to the sea by the rivers of the world will not be immediately precipitated, but will come to rest in ocean depths and not close in shore.

EXPERIMENTAL PRECIPITATION OF FINE CLAY.

METHODS ADOPTED.

We prepared at the outset water of standard turbidity, that is to say, water in which the weight of fine clay* in a measured volume was known, also solutions wherewith to precipitate the clay from it. First of all equal weights of several varieties of clay from the Isle of Wight and elsewhere were mixed so as to have an average specimen. We shall call it "the composite clay." It was washed with well diluted acid, and next with water, to remove any gypsum and other soluble matter, and then suspended in a considerable volume of distilled water for the sand and coarse particles to settle. After eight hours' rest the upper liquid was syphoned off and the clay in it found by evaporating a measured volume to dryness (120 degrees C.) and weighing the residue. Measured portions suitably diluted provided two standard waters containing respectively—

50 parts of fine clay per 100,000 of water,

1,000 parts of fine clay per 100,000 of water.

Of so fine a texture was the clay in both that little settled in 24 hours. Indeed the uppermost layers of liquid have not quite cleared after some months' repose.

The following precipitants were used:—

* As the term clay is understood by Geologists.

Sea water, collected for us by Mr. Treleaven Reade between the Welsh coast and the Isle of Man.

Sea water diluted, called here *marine precipitant.*

Calcium di-carbonate.

Calcium sulphate (gypsum).

The precipitants were so adjusted that 100,000 parts should contain 50 parts respectively of sea salts, calcium di-carbonate and calcium sulphate. They thus held as much reacting salts in *solution* as the weaker clay water held clay in *suspension.*

An experiment in clay flocculation consisted in mixing exactly equal volumes of the well shaken muddy water and precipitant, and in noting the effect produced alongside blank tubes, *i.e.*, alongside tubes of clay water without precipitant. Experiments were conducted at the air temperature and at higher temperatures. Blank experiments were seldom required, for flocculation in their case did not occur during the observational period either in the cold or when warmed. Precipitations were made in glass cylinders. After addition of precipitant the glasses were stood, as the case might be, either on the bench or in water of 41·6 degrees C. (107 degrees F.) or higher temperature. A few trials only were made with 50 clay per 100,000 just to observe the mechanics of the flocculation which could be more easily watched in the less turbid water.

EXPERIMENT 1.—*25 cubic centimètres of the 50 clay water added to 25 c.c. of marine precipitant cold.* Some clearing at surface in 1½ hours. All but the finest flocks settled in 3 hours. Some flocks adhered to sides of cylinder. Repeated with same result.

EXPERIMENT 2.—*Calcium di-carbonate precipitant, same proportions cold.* Visible coalescence of clay particles at the end of 1 hour.

EXPERIMENT 3.—*Gypsum precipitant, same proportions cold.* Action much the same.

The tubes, examined with a lens, showed flocculated particles of varying size, adherent to their sides. This was more noticeable in some tubes than in others. The upper fluid was in all cases slightly opalescent. The weak clay water was discarded after repeating the experiments:

EXPERIMENTS WITH THE 1000 PARTS OF FINE CLAY PER 100,000 OF WATER:—

EXPERIMENT 4.—*25 c.c. of clay water to 25 c.c. of marine precipitant, cold.*

The liquid cleared much in 5 minutes. In 15 minutes the deposit had a thickness of 3 m.m. In a blank experiment scarcely any clay fell in the same interval. All but the finest particles settled in 2½ hours. A repetition gave nearly the same result. The liquid showed signs of clearing at the surface in 3 minutes, and much deposit fell in 8 minutes.

EXPERIMENT 5.—*25 c.c. of clay water to 25 c.c. of sea water alongside same clay water mixed with 25 c.c. of marine precipitant. Both tubes were started simultaneously, cold.*

The tube with sea water began to clear in 4 minutes, and more deposit fell in 8 minutes than fell in the comparison tube in 15 minutes. Repetitions gave the same result.

EXPERIMENT 6.—*25 c.c. of clay water to 25 c.c. of calcium di-carbonate, cold.*

The liquid did not clear as quickly as with the marine precipitant. Two simultaneous experiments showed more deposit in 10 minutes for the marine precipitant than fell in 20 minutes for the di-carbonate. The observation was confirmed on repetition.

EXPERIMENT 7.—*25 c.c. of clay water to 25 c.c. of gypsum precipitant.*

The liquid began to clear in from 10 to 12 minutes. All clay was down in 2½ hours, leaving upper liquid grey.

The late Professor Dittmar's analyses of sea water got during the voyage of the *Challenger** show that in specimens collected in the North Atlantic the marine salts amount to 3·737 per cent.

Taking his figures, the weights of marine salts and fine clay in the 50 cc. of liquid in our several cylinders will have been approximately—

Fine Clay in 25 c.c. of Clay Water.	Salts in 25 c.c. of Sea Water.	Salts in 25 c.c. of Marine Precipitant.
0·25	0·970	0·0125 Grammes.

Inasmuch as the "marine precipitant" very efficiently flocculated the clay, it would appear that 0·0125 parts of

* Report of Voyage of the "*Challenger*," 1884, Vol. I.

sea salts will throw down 0·25 parts of clay. In other words, one part of sea salts will precipitate 20 times its weight of clay. Much less will, however, do so, as will now appear. When the proportion of sea salt was 1 to 100 of clay, flocculation did not begin for 30 minutes, but once started, much deposit fell in $2\frac{1}{2}$ hours. The reaction between the salts and the clay, though delayed, was at its close complete. It appeared to us that a limit of precipitation was reached when the proportion of sea salt to clay was about 1 to 250, for although slight flocculation occurred in a few hours, settling was incomplete in ten hours. The turbid liquid, however, cleared much more completely in 18 hours than a blank experiment did in the same interval.

A fact attesting the small weight of precipitant competent to flocculate clay was disclosed by the calcium dicarbonate experiments. Taking two cylinders, in each of which 0·25 grms. of clay had been thrown down by 0·0125 grms. of the calcium salt, and filtering off the upper liquid, we found that the filtrate deposited calcium monocarbonate when boiled. This shows that small as the original amount of di-carbonate was relatively to the clay, the latter on precipitation did not remove all the dicarbonate from the field of the reaction. A further confirmation of this fact was got by adding some of the filtrate to a fresh portion of clay water, which it flocculated in a few hours.

Experiments with other Clays.

They were prepared just as the composite specimen. The proportion of fine clay to water being 1,000 per 100,000 as before.

No. 2.—Wealden Clay from Brook Chine, Isle of Wight.

EXPERIMENT 8.—*25 c.c. of clay water added to 25 c.c. of marine precipitant, cold.*

Slight clearing at surface in 17 minutes. Not much deposit in 50 minutes. Did not clear as quickly as the composite clay, though it did so completely in 3 hours. The deposit in 24 hours was 13 m.m. thick, as against 3 m.m. for the composite specimen. Thus the Wealden clay gave a more bulky deposit for same weight of clay in cylinder.

Calcium di-carbonate and gypsum precipitants gave similar results.

No. 3.—Ferruginous Clay from the foot of Bala Lake, North Wales. (Recent deposit—not tabulated).

This is a fine soft clay when wet, of a reddish colour. A purely lake deposit.

EXPERIMENT 9.—*25 c.c. of clay water added to 25 c.c. of marine precipitant. Cold.*

Cleared much in 12 minutes. There was 2½ m.m. of deposit in 20 minutes. It finally cleared completely. In 24 hours the deposit measured 3 m.m. or thereabout. The upper liquid was then grey, having completely lost its earlier reddish tint.

Alluvium (Recent Deposit—not tabulated), collected by bridge on the Dee between Llanderfel and Llandrillo.

A dark grey deposit of a sandy nature. This specimen contained but little clay. The fine stuff washed from it was chiefly "rock flour," which settled at once. A clay water prepared from this alluvium behaved with the precipitants just as did that from the composite clay.

These two specimens, both from the basin of the River Dee, show clearly the difference between river and lake deposits. No. 3 ferruginous clay was gathered from the deposit at the foot of Bala Lake, where rushes and much vegetation grow. There is a natural drift of leaves and branches of trees to the foot of the lake, and the combined decay of these fragments of vegetation, together with the at times quietude of the waters, induces this settlement of the finer detritus, the origin of which is to be found in the decay of the slaty and mostly non-calcareous rocks of the watershed. The felsitic rocks of

the Arans also contribute their quota. The coarse alluvium of the Dee below the lake at Llanderfel is deposited by swiftly-flowing water, yet there still remains a residuum of a finer nature analogous to the lake deposit.

We have said that the liquid in our tubes cleared in from $2\frac{1}{2}$ to 3 hours. This was so as regards the bulk of the clay. The upper liquid after three hours' rest had usually a milky appearance. This milkiness we found to be largely due to quartz dust that had not been gathered and precipitated by the subsiding clay. Angular fragments of quartz with mica were easy of recognition in the liquid when examined with a $\frac{1}{4}$ inch power. There was often a little clay also which had not quite deposited.

Increase of Temperature assists Flocculation of Clay by Precipitants.

EXPERIMENT 11.—*25 c.c. of clay water (composite clay) added to 5 c.c. of marine precipitant, equal to 0·0025 grms. of sea salts, temperature 26·6° C. (80° F.)*

Much clearing in 20 minutes. In the cold tube there was less clearing in 40 minutes. Convection currents in the warmed tube, by reason of their churning motion, will doubtless tend to coalesce the clay particles.

Heating the clay water *alone* to 41·6 degrees C. (107 degrees F.) for an hour, and then setting the tube in water of 10 degrees C. (50 degrees F.) *did not* induce flocculation, but subsequent addition to the tube of any one of the precipitants did so in due course.

Boiling the clay water *alone* for two minutes and then allowing it to stand in water of 10 degrees C. for three hours did not induce flocculation. A precipitant, however, threw down the clay as before.

EXPERIMENT 12.—*25 c.c. of clay water added to 25 c.c. of water supplied to London house (New River Co.), warmed to 41·6° C. for 10 minutes.* On cooling the tube, more clay fell in 10 minutes than fell in 20 minutes in an unwarmed tube. (The New River water contains calcium di-carbonate).

No. 3.—Ferruginous Clay, Bala Lake. (Recent Deposit—not tabulated).

EXPERIMENT 13.—*25 c.c. of clay water added to 25 c.c. of marine precipitant, warmed at 41·6° C. for 10 minutes.*

Cleared considerably in 5 minutes. An unwarmed tube did not clear to the same extent in 12 minutes. There was 3 m.m. of deposit in 7 minutes in the warmed tube.

VARIATION IN THE AMOUNT OF SUSPENDED MATTER OBTAINED IN THE CYLINDER EXPERIMENTS AFTER 18 HOURS' REPOSE.

Reference to the Table will show that for some sediments which have points in common, the yield of suspended matter varies considerably. Sediments rich in clay usually yield a high figure, as might be predicted, but this is not invariably the case. Examples to the contrary are furnished by "Gault clay *in situ*," "The slipped Gault," "Purple clay, Alum Bay," "Black clay, Alum Bay," clay from Apse Hill, and residual clay, Bonchurch Downs. These specimens gave respectively the following percentages of "potential clay" and suspended matter:—

Clay.	Suspended Matter.
34·67	1·60
23·72	12·10
43·57	2·58
26·08	1·19
28·26	5·64
39·47	6·49

Why some sediments so rich in clay should yield so little suspended matter when diffused in water, is not at this stage of the enquiry at all apparent. Had they contained much gypsum, this mineral, being soluble in the water of the cylinder, would, as our precipitation experiments show, have caused early settling of the fine clay.

When these investigations were begun, it seemed probable that a ratio might be found to exist between the percentage of clay in sediments and their yield of suspended matter; but experiment has not confirmed the surmise. We must, however, leave the problem for the present.

THE CO-PRECIPITATION OF FINE CLAY AND CHALK BY SEA WATER.

In an earlier part of this communication we spoke of the delayed subsidence of fine chalk in brine, and instanced Mr. Higgin's observation at the Anderton Salt Works, Northwich. This observation led us to experiment on the co-precipitation of fine chalk and clay by marine salt since the question is one bearing on the relative dispersal of suspended chalk and clay which rivers bring to the sea. The object, then, of the experiments now to be described was to learn how much chalk, when present with clay, escapes being gathered by the clay when the latter is thrown down by sea water.

The clay water was made with the composite clay. To it was added finely levigated chalk, so as to give the following proportions:—

	1.	2.	3.
Clay ...	1,000 ...	1,000 ...	1,000
Chalk ...	1,000 ...	500 ...	250
Water ...	100,000 ...	100,000 ...	100,000

A 100 C.C. of each of the above, and the same of sea water, were mixed and the mixture allowed to stand. Flocculation was quick and decided. When the clay had settled, the upper milky fluid was decanted, and the still suspended chalk determined in an aliquot portion, taking care to make due correction for the lime present in the added sea water.

Chalk found in parts per 100,000 of water after the clay was precipitated by the sea water.

	1.		2.		3.
	14·70	...	9·10	...	3·70
	9·10	...	9·50	...	8·00
	11·90	...	7·50	...	5·20
	13·50	...	10·30	...	7·50
	13·90	...	9·90	...	4·40
	17·50	...	11·90	...	5·20
	12·70	...	9·70	...	—
	16·70	...	—	...	—
Mean	13·7	...	9·7	...	5·6
Grains per Imperial Gallon ...	9·59	...	6·79	...	3·92

These experiments are instructive, inasmuch as they show the inability of an amount of clay largely exceeding that of the chalk to gather all the chalk when the clay is thrown down. The experiments will bear on the action of sea water on river mud holding chalk in suspension, for if clay in vessels at rest cannot gather all the chalk, it will be less likely to do so when under the influence of tidal currents. Thus the retention of chalk particles in the sea water for periods sufficiently long to ensure widespread deposit of inorganic calcium carbonate over the oceanic floor becomes extremely probable.

Analyses of the Sediments Collected in the Isle of Wight and Elsewhere.

A modification of the sifting operation described in Part I., p. 378, has been necessary for sediments of the character dealt with in the present communication. Clean dry sands can be readily sifted; not so cohesive sediments. These are best washed on the sieves to free the residual sand from adherent clay. A house painter's brush much assists the process. The sieve with the weighed sediment was placed in a lipped bowl of water, and the washings from the first sieve were passed through the second, and these in turn through the third sieve. What sand the sieves retained was dried on them, care-

fully collected, and further dried at 120 degrees C. and weighed. The unretained fraction was not weighed. The percentage was found by difference. It is well to take not less than 100 grammes of a sediment, as this reduces the error attaching to a somewhat rough operation. The results for the same sediment are fairly concordant. What passes the 90 mesh and makes up the bulk of sediments is chiefly clay, so-called. The sands which the sieves retain have not been petrologically studied. Examination by an expert in such work might possibly have indicated the rocks concerned in forming the sediments of which they themselves are the residue. The occurrence of mica on the 90 mesh is quite common, though some will pass through, however gently the brush may have been used.

The following analyses are of some of the sediments themselves, and of the fine stuff held in suspension for 18 hours. Material for analysis was in all cases dried at 120 degrees C. till of constant weight. Some of the analyses were made in duplicate:—

	No. 1.—Oxford Clay.	The 18 Hour Suspended Matter.
Total SiO_2	37·87	44·91
TiO_2	0·69	0·81
Al_2O_3	14·79	23·30
Fe_2O_3	2·02	3·79
FeS_2	1·86	—
FeO	0·97	0·57
MnO	present	present
CaO	18·58	7·92
BaO	present	—
MgO	1·04	1·70
K_2O	2·54	3·53
Na_2O	0·38	0·52
CO_2	14·39*	6·11
SO_3	0·14	none
P_2O_5	0·09	0·12
Carbonaceous Matter	1·16	—
Combined Water...	3·37	Combined Water and Rest 6·72
	99·89	100·00

* Equal to 32·7 $CaCO_3$.

A provisional arrangement for the mineral composition of the suspended matter is set out in the annexed Table:—

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	K_2O	Na_2O	CO_2	P_2O_5	H_2O	Sum
Mica	16·49	14·02	—	—	—	—	3·53	0·52	—	—	1·64	36·20
Chalk	—	—	—	—	—	7·77	—	—	6·11	—	—	13·88
Clay	9·71	8·26	—	—	—	—	—	—	—	—	2·91	20·88
Pyroxene	1·81	1·02	—	0·57	1·70	—	—	—	—	—	0·72	5·82
Limonite	—	—	3·79	—	—	—	—	—	—	—	0·63	4·42
Calcium Phosphate	—	—	—	—	—	0·14	—	—	—	0·12	—	0·26
Quartz	16·90	—	—	—	—	—	—	—	—	—	—	16·90
Rest	—	—	—	—	—	—	—	—	—	—	—	1·64
Sum	44·91	23·30	3·79	0·57	1·70	7·91	3·53	0·52	6·11	0·12	5·90	100·00

Allowing 36 instead of 18 hours' repose gave a suspended matter in which the chalk and real clay were found respectively to be 16·8 and 18 per cent., showing the tendency of fine chalk to remain long in suspension after other matter had subsided.

No. 4.—Slipped Gault, Cliff Farm brickfield.

Analysis of the 18-hour suspended matter.

			Provisional Mineral Composition.	
Total SiO_2	... ...	70·50	... ...	—
TiO_2	... ...	0·43	... ...	—
Al_2O_3	... ...	13·54	... ...	—
Fe_2O_3	... ...	5·10	... ...	—
FeO	... ...	0·21	... ...	—
MnO	... ...	traces	... ...	—
CaO	... ...	1·14	... Mica	18·96
MgO	... ...	1·19	... Clay	13·96
K_2O	... ...	1·66	... Limonite ...	5·96
Na_2O	... ...	0·40	... Pyroxene ...	3·69
CO_2	... ...	0·90	... Chalk	2·03
Carbonaceous Matter	...	0·95	... Quartz ...	54·15
Combined Water	...	4·19	... Rest	1·25
		100·21		100·00

The two next analyses are of the clays.

No. 5.—A and C of the London Basin.

		A.	C.
Total	SiO_2	61·74	60·67
	TiO_2	0·97	1·50
	Al_2O_3	16·92	19·33
	Fe_2O_3	4·22	6·32
	FeS_2	1·72	0·13
	FeO	1·07	0·54
	MnO	0·11	0·10
	CaO	1·00	0·95
	BaO	0·07	0·05
	MgO	2·93	1·44
	K_2O	3·27	3·06
	Na_2O	0·57	0·51
	CO_2	0·14	0·10
	SO_3	0·22	0·03
	P_2O_5	0·09	0·13
Combined Water and Carbonaceous Matter not estimated		4·96	5·14
		100·00	100·00

These two clays have a somewhat similar bulk composition. The figures in the Table, however, show differences of 3 per cent. for the matter soluble in acid, and $8\frac{1}{2}$ per cent. for suspended clay. Specimen C is slightly coarser and is of higher gravity. The ferric oxide is 2 per cent. more in this specimen, whilst the pyrites is 1·6 per cent. less.

The next analysis is that of B, the "blue marl." On treating this deposit with diluted acid a considerable amount of silicic acid is set free, which remains temporarily dissolved in the liquid. Inspection of the analytical figures will show that the weights of the CO_2, SO_3, and P_2O_5 are insufficient for all the lime, and that a balance remains of 31·61 per cent. of this oxide, which is doubtless present as silicate. The silicate will probably have been formed *in situ* by infiltration of silicic water from overlying beds of clay.

ANALYSIS OF *B*, No. 5.

Total	SiO_2	16·93
	TiO_2	0·27
	Al_2O_3	5·89
	Fe_2O_3	3·46
	FeO	0·57
	MnO	0·07
	CaO	47·68
	BaO	0·03
	MgO	2·11
	K_2O	1·17
	Na_2O	0·35
	CO_2	10·55
	SO_3	3·64
	P_2O_5	0·08
Carbonaceous Matter	... ...	0·30
Combined Water	... ...	7·02
		100·12

Our concluding analysis is one of the Wealden clay.

Analysis of the Wealden Clay from Brook Chine, Isle of Wight.—No. 2.

The Original Clay.		The 18 Hour Suspended Matter.		Provisional Mineral Composition of Suspended Matter.	
Total SiO_2 ...	63·64	... ...	50·53	... ...	—
TiO_2 ...	1·22	... ...	1·06	... ...	—
Al_2O_3 ...	19·25	... ...	28·81	... ...	—
Fe_2O_3 ...	7·51	... ...	5·44	... ...	—
FeO ...	none	... ...	—	... ...	—
MnO ...	0·11	... ...	0·09	... ...	—
CaO ...	0·52	... ...	0·47	... ...	—
BaO ...	0·02	... ...	—	... ...	—
MgO ...	0·69	... ...	1·05	Mica	36·86
K_2O ...	1·93	... ...	2·99	Clay	35·19
Na_2O ...	0·50	... ...	0·94	Limonite ...	6·35
CO_2 ...	0·13	... ...	0·37	Pyroxene ...	3·08
SO_3 ...	0·05	... ...	—	Chalk	0·84
P_2O_5 ...	0·08	...	not sought	Quartz... ...	16·24
Water and Organic Matter not estimated	— 4·35	Organic Combined Water	0·58 7·92	Rest	1·44 —
	100·00		100·25		100·00

For calculating the mineral composition of the suspended matter, the alkali—soda partly replacing potash—has been entirely allotted to mica, the ferrous and magnesian oxides to chlorite, and the balance of alumina to clay, whilst the ferric oxide has been reckoned as limonite. The figures for alkali are the mean of two estimations by the lime fusion plan. The combined water was got by strong ignition, collecting the expelled water in a tared absorption tube in the usual way. We wish it to be clearly understood that the distribution of the oxides is quite provisional, and is to be looked on as a device to aid the inter-comparison of the sediments as regards their chief constituents, and not as a full account of the minerals in them.

Many of the sediments, when heated to redness in a glass tube in a slow current of CO_2 gave a slight but distinct ring of sublimate on the cool part of the tube. This sublimate was a salt of ammonia. We mention the fact because it is on record that $\frac{4}{100}$ per cent. of NH_3 has been detected in slate and other rocks. Luedeking found ammonium sulphate in a barite from Missouri, the presence of which W. H. Hillebrand, of the U.S.A. Geological Survey, was able to confirm.*

The occurrence of ammoniacal salt in slate suggests that it may be genetic in the rock, belong to the organic matter of the original sediment, and not be externally acquired by the slate at a later geological epoch.

Concluding Observations.

The experiments now detailed raise so many questions of physical and geological interest that this communication is all too short to attempt to deal with them. That

* Bulletin of the United States Geological Survey, 1900, No. 176, p. 107.

there are many obscure causes that operate in differentiating sediments, besides the purely mechanical and strictly chemical causes, we trust our work will have conclusively shown.

It will be our endeavour in future researches to evolve some principles from these multitudinous and often apparently contradictory facts, and to strengthen, if need be, the suggestions already thrown out in our two communications.

DETAILS

		No. 6.		No. 14.		No. 15.	
C.		Clay near B under Lime bed, North o Colwell B Isle of Wi		Residual Clay from Gravel of Chalk Downs, Bonchurch Down, Isle of Wight.		Indurated Pleistocene Sand, Brook Chine, Isle of Wight.	
2		2·708		2·656		2·628	
	Sp. Gr.		Sp.		Sp. Gr.		Sp. Gr.
	—	0·37		2·50	2·625	None	—
	—	2·85		2·80	2·714	0·18	—
	—	4·27		3·10	2·686	6·08	—
	—	92·51		91·60	2·603	93·74	—
	—	47·64		13·66	—	2·46	—
	—	5·64		15·57	—	3·31	—
	—	0·56		0·54	—	0·30	—
	—	3·04		4·65	—	2·11	—
	—	14·29		39·47	—	8·39	—
	—	8·53 (8) and		6·49	—	3·94	—

(7) Contai

(8) ,,

PROCEEDINGS

OF THE

Liverpool Geological Society

SESSION THE FORTY-SEVENTH,

1905-1906.

Edited by R. W. BOOTHMAN ROBERTS, F.G.S.

(The Authors having revised their own Papers, are alone responsible for the facts and opinions expressed in them.)

PART 2. VOL. X.

LIVERPOOL:
C. TINLING AND CO., LTD., PRINTERS, VICTORIA STREET.

1906

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ADDITIONS TO THE LIBRARY OF THE LIVERPOOL GEOLOGICAL SOCIETY, 1905-6.

The usual Proceedings and Transactions of the various Scientific Societies have been received for the Library of the Society during the past Session, also:—

British Association Report, 1905.—South African Meeting.

California University.—Bulletins of the Department of Geology, 1893-1905.

Geological Survey of the United Kingdom :—
"Summary of Progress for 1904."
"Geological Map of the British Isles, 1906."

List of Works by Baron von Richthofen, 1856-1905.

Palæontographical Society.—Vol. lix., 1905.

Smithsonian Institution.—Annual Report, 1905.

"The Naturalist," 1905.

United States Geological Survey :—
Annual Report, 1904.
Monograph, xlviii.
Mineral Resources, 1904.
Folio Atlas Sheets.
Professional Papers, &c.

PROCEEDINGS

OF THE

LIVERPOOL GEOLOGICAL SOCIETY.

SESSION FORTY-SEVENTH.

OCTOBER 10TH, 1905.

THE PRESIDENT, H. C. BEASLEY, in the Chair.

The Officers and Members of Council for the Session were duly elected.

THE HON. TREASURER gave his Annual Statement of Accounts, which was unanimously adopted.

EXHIBIT :—

A Facetted Pebble from the Boulder Clay near Ormskirk, by W. D. BROWN.

THE PRESIDENT, H. C. BEASLEY, read his Annual Address :—

"SOME DIFFICULTIES OF THE UPPER KEUPER."

OCTOBER 23rd, 1905.

THE PRESIDENT, H. C. BEASLEY, in the Chair.

The Meeting was held in the Lecture Theatre of the Royal Institution, and was open to the public.

The following Paper was read:—

"The Canons of the Colorado and their Lessons."

By Professor W. M. Davis, of Harvard University.

NOVEMBER 14th, 1905.

The President, H. C. Beasley, in the Chair.

A Vote of Condolence was passed to the Widow of Baron von Richthofen, of Berlin, for many years a Foreign Corresponding Member of the Society.

Walter Schofield, 3, Ampthill Road: proposed by H. C. Beasley and W. A. Whitehead, B.Sc., was elected an Ordinary Member.

Exhibit:—

A Curious Incrustation in a Wooden Pipe, locality unknown, by J. Lomas, F.G.S.

The following Paper was read:—

"The Pleistocene Clays and Sands of the Isle of Man."

By T. Mellard Reade, F.G.S., and Joseph Wright, F.G.S.

DECEMBER 12th, 1905.

The President, H. C. Beasley, in the Chair.

The Meeting was held in the Lecture Theatre, and was open to the public.

A Lecture, entitled, "With the British Association in South Africa," was given by J. Lomas, F.G.S. (The Lecture was illustrated with Lantern Slides.)

JANUARY 9TH, 1906.

THE PRESIDENT, H. C. BEASLEY, in the Chair.

A. WARD, 104, Selborne Street: proposed by J. LOMAS, F.G.S., and W. A. WHITEHEAD, B.Sc.; A. W. HARRIS, B.A., 61, Brookdale Road: proposed by J. LOMAS, F.G.S., and W. A. WHITEHEAD, B.Sc., were elected Ordinary Members.

EXHIBITS :—

A Slab of Sandstone, with tracks, from near Paisley, by J. BRUCE, M.A.

Jaws and Teeth of Ichthyosaurus, from Coventry, by W. GOULDSON.

The following Paper was read :—

"THE DWYKA OF SOUTH AFRICA"

(With Lantern Illustrations).

By J. LOMAS, F.G.S.

FEBRUARY 13TH, 1906.

THE PRESIDENT, H. C. BEASLEY, in the Chair.

EXHIBIT :—

Estheria and Plant Remains, from St. James' Cemetery, by W. SCHOFIELD.

The following Paper was read :—

"THE PEBBLES OF THE BOULDER CLAY."

By W. D. BROWN.

MARCH 13TH, 1906.

THE PRESIDENT, H. C. BEASLEY, in the Chair.

The award of the "Barlow Jameson Fund" to the President, H. C. BEASLEY, by the London Geological Society, was recorded in the Minutes.

EXHIBIT :—

Fossils from the Kimmeridge Clay of Market Rasen, by J. LOMAS, F.G.S.

The following Paper was read :—

"THE PYRENEES AND THEIR GLACIERS."
(With Lantern Illustrations).

By E. DICKSON, F.G.S.

APRIL 10TH, 1906.

THE PRESIDENT, H. C. BEASLEY, in the Chair.

EXHIBITS :

Tracks of Crustaceans from Irby, by W. SCHOFIELD.

Bone (unknown), from Peat Bed at Leasowe, by J. H. MILTON.

The following Paper was read :—

"SANDS AND SEDIMENTS" (PART III.)

By T. MELLARD READE, F.G.S., F.R.I.B.A., and PHILIP HOLLAND, F.I.C.

FIELD MEETINGS :—

1905.

June 3.—Stanlow and Ince.

Leader—J. LOMAS, F.G.S.

June 17.—Hilbre Island (Joint Excursion with the Liverpool and Manchester Biological Societies.)

Leader—Professor W. A. HERDMAN.

Aug. 26.—Castleton, Derbyshire.

Leader—W. J. DAKIN, B.Sc.

Sept. 23.—Hope Mountain.

Leader—H. C. BEASLEY.

1906,
Feb. 24.—Kirkby.

Leader—J. LOMAS, F.G.S.

Apr. 13 to 16.—Uttoxeter and District.

Leader—H. C. BEASLEY.

EASTER EXCURSION, 1906, TO UTTOXETER AND DISTRICT.

Leader—H. C. BEASLEY, *President.*

The party left Liverpool on the afternoon of April 12th, and took up their quarters at the White Hart Hotel, Uttoxeter.

April 13th. By rail to Norbury, walking thence by way of Ellastone and Ousley Cross to Stanton, 900 ft. O.D., where there are quarries in the Keuper Sandstone. Thorley's quarry showed about 20 ft. of red clay full of limestone boulders, overlying the sandstone, the surface of the latter being striated. A very good example was just exposed.

At Ford's quarry, the foreman, Mr. J. Bradshaw, pointed out the position where the head of Capitosaurus Stantonensis was found a few years ago. No further fossils have been found, nor were there any footprints except very imperfect traces of small ones. The workings extend towards the fault which brings up the Yoredales and Carboniferous Limestone on the North, but not far enough to expose it. From there, Mr. Bradshaw led the party across the fields to a fine exposure of Limestone in a small and very picturesque gorge about a mile distant. A few fossils were found but no exposure of the junction of the Trias and Carboniferous Limestone.

Returning to Stanton to tea, a visit was then made to some rows of unhewn stones of apparently great age.

April 14th. The North Staffordshire Field Club had arranged a joint excursion with our society, Mr. F. Bark, F.G.S., of the Field Club. acting as leader. Driving from Uttoxeter, the first halt was on the top of the hill at Hollington, where there are numerous quarries in the Keuper Sandstone. The stone is light in colour and durable, somewhat resembling that of Storeton, and much in request in the Midlands. Mr. Stevenson and Mr. J. Fielding, quarry owners, met us, and a couple of hours were spent in the various quarries. The first visited was the one in which the abdominal ribs of Hyperodapedon were found early in the year. Mr. Lomas gave a short address sketching the theory of the formation of the Triassic sandstones and footprints. In the quarry next visited some footprints of an apparently new form were soon discovered on some slabs of flaggy sandstone. At first sight they resembled the three-toed prints found in Connecticut valley, but were found to have two other smaller toes pointing outwards and backwards. The slab was at once presented to the North Staffs. Field Club, and is now in the Hanley Museum. A few other examples of the same form were found as well as Cheirotheroid and Rhynchosauroid prints.

Some of the party walked by the way of Mr. Stevenson's red sandstone quarry near Great Yate and others by a more direct route across the fields, to the ruins of Croxden Abbey. Here, Mr. Scrivener, Vice-President of the Club, gave a short history of the Abbey and then conducted the party over the ruins and the excavations in progress to trace the foundations of the original building. The next halt was at Alton where, having viewed the gorge of the Churnet from the grounds of the Convent crowning the cliffs on the right bank, we were taken along the base of the crag. Here the Lower Keuper, with a hard conglomerate at its base, rests on a soft sandstone with a very few pebbles. At Mr. Fielding's quarry near the Convent, considerable interest was taken in the roof of one part of the excavation which was covered with the reticulated markings of dessication cracks in an underlying bed of clay which had been removed. Other quarries in the village showed 10 to 20 ft. of Upper Keuper Marls resting directly, without transition, on a level surface of the building stone.

From Alton we drove back to Uttoxeter without further halt.

April 15th. By train to Ashbourn and walk to Dovedale, where the day was spent.

April 16th. By train to Alton and then on foot along the Okeamore road, where sections of the Bunter conglomerate were seen. Thence through Dimmingsdale, a richly wooded gorge, with crags of Lower Keuper crowning the slopes of Bunter. Beggar's Well quarry was examined and then, by way of lanes and fields, Peakstone Rock was visited. This is a mushroom shaped rock, some 15 ft. high, standing alone on the flat top of the Keuper escarpment. It is said to owe its preservation to the presence of a quantity of barium sulphate. Thence through the village of Bradley to the red sandstone quarry at Great Yate. What looked like a glacially grooved surface underlying 8 ft. of rock was here seen, and was doubtless caused by the horizontal movement of the upper beds. A second visit was then paid Hollington, and other quarries not seen on the Saturday excursion. A good glaciated surface was seen. A walk by field paths back to Uttoxeter closed the Society's excursion.

H. C. Beasley.

THE LIVERPOOL GEOLOGICAL SOCIETY, in Account with W. H. ROCK, Hon. Treasurer.

Dr. SESSION 1904-1905. **Cr.**

Dr.	£	s.	d.
To Rent, October, 1904, to October, 1905..	5	0	0
,, Tinling & Co.—Printing for Session ...	7	6	8
,, Tinling & Co.—Proceedings, Session 1903-1904	20	9	6
,, Tinling & Co.—Proceedings, Session 1904-1905 (not complete)	0	0	0
,, Mrs. Ellick—Teas and attendance, &c.	5	13	3
,, Secretary's, Librarian's and Treasurer's Expenses	3	19	1
,, Geological Magazine for Session	0	18	0
,, Palæontographical Society, 1904	1	1	0
	£44	7	6
,, Balance carried down	19	4	9
	£63	12	3

Cr.	£	s.	d.	£	s.	d.
By Balance from Session 1903-4				14	13	9
,, Subscriptions, &c., received:—						
1903-4—Arrears	£2	4	6			
1904-5—Subscriptions ...	42	15	6			
Printing Fund	1	11	0			
Sales	0	5	6			
1905-6—In Advance......	2	2	0			
				48	18	6
				£63	12	3
9th Oct., 1905. By Balance				£19	4	9

Audited and found correct,

(Signed), HENRY CAPPER, GEO. H. ASHWORTH, } Auditors.

(Signed), W. H. ROCK, Hon. Treasurer.

Liverpool, *9th October, 1905.*

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LIVERPOOL GEOLOGICAL SOCIETY.

PRESIDENT'S ADDRESS.

10TH OCTOBER, 1905.

I should like, before coming to the more technical part of this address, to say something about the position of this Society as a part of the educational machinery of this city. Strictly speaking, perhaps, it is not a part of the actual machinery, but, in common with the other Societies connected with this Institution, one of its functions is to assist in the higher education of the citizens of Liverpool.

We have at last realised the fact that in technical education we are behind other countries, and that although we have so far made up for the want of it by the superior ability of our workers as a whole, we must give them the advantage of this also if we are to hold our position. For this reason the technical side of education has of late years been the first consideration. It must, however, not be forgotten that this technical knowledge cannot take the place of culture and learning in its older sense, but is something that must be acquired in addition to it.

The struggle for wealth, or even for the very means of existence, has no business, in any civilized community, to be so severe as to exclude the pursuit of intellectual culture in some form, otherwise we must sink back into barbarism. It was this idea that actuated those who formed this Institution and promoted the formation of

the Societies meeting here—Societies which, when there was no University, College, or Municipal Museum, kept alive the desire for some learning other than technical, a learning that would be a relaxation and rest after the day's work, but which would at the same time enlarge men's mental outlook and bring them more or less into touch with the great realities of the Universe.

Amongst these Societies, ours has, I hope, done its fair share of useful work. With the foundation of University College and the University of Liverpool a new era was inaugurated, and instead of only the members of our Societies the whole community was to be imbued with a feeling of the importance of intellectual culture—and I think that expectation is in a fair way of being realised.

This, however, by no means does away with the usefulness of such Societies as ours; in fact, they still have the same work to do as formerly.

There are two other educational institutions of much later date than these Societies, and those are the magnificent Free Public Museum and Library. The help afforded by them to education throughout the city is acknowledged on all hands, and by none more than by the Societies who could not possibly carry on their work as they do without them.

Where the bulk of the work done by the middle classes is necessarily, as it is in Liverpool, done without much physical exertion, and in a more or less stagnant atmosphere, there will always be an objection, especially on the part of young men, to any "hobby" that has to be carried on under the same conditions as those of their working hours, such as is the case with literary work, for instance. But the study of an "Out-of-door Science," such as Natural History, be it in the form of Zoology, Botany, or Geology, especially the latter, is free from this drawback.

Of the great advantage of Geology as an instrument of mental cultivation I need not speak here, familiar as it is to all of us, and it is this that makes us regret that it does not take the position at our University that we think it deserves. We may hope, however, that with the opening of the new home for the Derby Chair of Natural History, Geology may take a better position than has hitherto been possible.

With regard to the Free Museum, the admirable way in which the vertebrate collection has been arranged and exhibited leads us to hope for an equally satisfactory exhibition of the geological collection, when the staff have time to turn their attention to that department, and in the meantime it would be unfair to criticise the present arrangement.

Whilst dwelling at this time on its educational functions, I have not forgotten that other function of this Society, viz., research. To some extent research must be in the hands of professional men, but hitherto amateurs have done their full share. It would be a great misfortune to science and to the community at large were that share allowed to grow less, and it rests with us and other kindred societies to see that it does not.

In choosing a subject on which to address you, at first, led away by a desire to open new ground, I had thought of the history of our district between the close of the Triassic deposits and the Glacial period. I thought such a subject would possess the advantages of both novelty and of interest, but on searching for some material I found that such was the dearth of facts that any address from me on the subject would be a pure work of fiction, such a draft on the imagination as would not be accepted even as a Presidential Address.

I have, therefore, been obliged to forego novelty and

fall back on the old, and one would suppose, threadbare subject of the Upper Keuper Marls.

A series of beds represented in a good proportion of the English Counties, of great economic importance, the source of the material of one of our great industries as well as of a domestic necessity all over the world, one would suppose to have been thoroughly investigated and the conditions of its formation to have been clearly made out. But we shall find that the teaching of our text-books on this subject is vague and the statements sometimes contradictory, and that the difficulties are not so fairly grappled with as in the case of some other periods of the earth's history.

My object to-night will be to point out some of these difficulties that have occurred to me, and possibly, in one or two instances, to make suggestions that may help others to remove them.

Although the proceedings of our Society abound in papers on the Bunter and the Lower Keuper, the Red Marl Series appears to have met with scant notice. This may have been due to the want of any sections of it of much importance in our immediate neighbourhood. The Red Marl of Wirral was supposed to represent only a very small portion of the lower beds, and of that north of Liverpool little was known; but we now know that its thickness in both areas is greater than was suspected.

The search for salt has, of course, been actively carried on, but the results of investigations for commercial purposes are naturally not usually placed at the disposal of possible competitors, and the result has been that we have rested content with the general idea that the Red Marls of South Lancashire and Cheshire are the result of sedimentation and evaporation in enclosed areas of sea water. A contented mind is a great blessing in many ways, but on the other hand discontent is the

starting-point of improvement and advancement in knowledge as in everything else.

The Upper Keuper is the uppermost member of the group of sandstones, conglomerates and marls that constitute the Triassic System some 6,000 to 7,000 feet in thickness in this district, of which, roughly speaking, the lower half consists principally of sandstones and conglomerates, whilst in the upper the marls greatly preponderate.

We have to begin with the soft sandstone of the Lower Bunter "f.1." of the Survey, succeeded by the harder sandstones and conglomerates of the Middle Bunter "f.2." which pass without any strong line of division into the soft sandstone of the Upper Bunter "f.3." The top of this in places shows signs of considerable erosion, and a decided dividing line separates it from the more or less conglomeratic beds at the base of the Keuper. But this does not necessarily mean any great intervening lapse of time. In fact, there are some signs of the mixing of the two deposits before the lower one became thoroughly consolidated. In all these divisions of the Bunter there are thin beds of marl, not always very continuous and of varying thickness.

The few feet of very irregularly bedded conglomerate at the base of the Keuper are succeeded by the Keuper building stone, with its thin beds of marl, followed in many places by a soft sandstone, the Frodsham beds, which repeat as it were the Upper Bunter. In some districts there is instead a gradual increase in thickness of the marl beds and decrease in that of the sandstone till the marl greatly preponderates. These intermediate beds are the waterstones. But where the Frodsham beds are present there is a sharp dividing line, the softer beds giving place to a hard, coarse bed of sandstone which marks the base of the waterstones and the division between the Lower and Upper Keuper. Between the

waterstones and the red marls we have no hard and fast line; as I said before, the marls gradually become the most important part, but still thin beds of sandstone, both grey and red, occur at irregular intervals. This is the succession in Cheshire, but, as you are aware, in other districts the lower members of the series are wholly or partially absent.

In Leicestershire the Red Marl reposes on and winds round the old rocks of Charnwood Forest, and along the border there is a mixture of angular fragments of these rocks at the base often forming a breccia. In the western counties, South Wales, and Bristol, it ends against the Carboniferous Limestone, fragments of which form what is known as the Dolomitic Conglomerate.

Intercalated beds of sandstone are found amongst the marl beds, some of them bearing the footprints of vertebrates and traces of invertebrates. A small crustacean, Estheria minuta, is found in certain localities, both in the marl and in the sandstone (but it should be noted that the beds containing it are not generally red, but of a light tea-green or grey colour). Still less frequently the remains of fishes are found in the sandstone; and in the upper beds, not far below the Rhœtic, foraminifera are said to have been found in the tea-green marls. (Quart. Jl. Geol. Soc., Vol. XV., p. 452, and Vol. XL., p. 771). I do not know of any record of their having been found elsewhere in this formation.

In the recently issued Memoir on the Country between Derby, Burton-on-Trent, Ashby-de-la-Zouch, and Leicester, by Mr. C. Fox Strangways, some doubts are expressed. He says:—"It has been stated that the "marls at Chellaston contain foraminifera, but owing to "the strong Liassic facies of the species it was always "doubted if they came from the drift which, no doubt, "is largely made up from debris of the Lias."

In Mr. T. R. Jones' paper (Q.J.G.S., Vol. 40, p. 771) on the Foraminifera and Ostracoda from the deep boring at Richmond, Surrey, he incidentally mentions that doubts have been expressed and that further search was without good result. Some of the same foraminifera were found in the boring at Richmond, but at several feet above the Poikilitic beds. So we may consider the presence of foraminifera in the Trias an open question.

In working out the history of sandstones and allied rocks there are three processes to be considered:—

I. The disintegration of the parent rock.

II. The transport of material.

III. Its distribution, that is to say, the placing of the different portions in their present relative position.

It may seem that II. and III. represent parts of the same process, but though this is frequently the case, it is by no means necessarily so. The material may be brought from a distance by rivers, by ocean currents, or by ice, for instance, but their local distribution may be effected by either of these other than that which transported them, and also by the action of wind. The movements and distribution of material may also be due to some extent to gravity. Mr. Blandford, in his account of certain districts of Persia, where the rocks are broken up by atmospheric action and the extremes of heat and cold, describes long slopes of debris, some from 5 to 6 miles long, from the foot of the cliff to the level of the plain, down which the material seems to be gradually moved by its own gravity assisted by the action of heavy rains at certain seasons.

I should recall to the recollection of this Society the Presidential Address of Mr. Hewitt, 1892,* dealing with

* Proc. L'pool Geol. Soc., Vol. vii., p. 11, Oct., 1892.

the Physical Conditions of Central Asia. On reperusing this paper, after a lapse of some years, I have been almost tempted to give up my present address, as Mr. Hewitt's paper so ably traverses the whole ground, and to that paper I can only refer whilst I touch on a few details in the light of 12 years' further discussion and research. With regard to the two first—the disintegration of the parent rock and the transport of material composing the great bulk of the Upper Keuper—but little need be said, as at the time of their formation a district of great extent was covered with surface accumulations, known to us as the Bunter and Keuper Sandstones and Conglomerates, quite sufficient to supply the material. But it is with its distribution mainly that we shall have to deal. It will, however, be as well just to glance at the theories that have attempted to account for these accumulations.

For a long time water alone was regarded as having in some form been the builder up of the whole series of Triassic rocks. In the older papers the sea and its tides were solely considered; then came the lacustrine theory and that of river action. Of late years the action of the wind has been seen to be an important factor which cannot be overlooked in the problem of distribution, but I can hardly see how wind, however strong, can have brought certain portions of the material into their present position, although perfectly able to bring them into their present condition.

Mr. T. Mellard Reade, in a paper on the Physiology of the Lower Trias,* maintained that the Bunter Sandstones had their origin in narrow seas with strong currents and shifting channels rather than by the action of rivers as advocated by Professor Bonney and others. The mass of the Bunter Conglomerate and Gravels in the Midlands he considered to have been a sea-beach in Triassic times.

* Geological Magazine, Dec., 1889.

With their origin the present paper has little to do, but the fact of the position and condition of the beds does concern us.

A large proportion of the pebbles are of quartzite, and have a beautifully smooth, almost polished, surface, such as could hardly have been produced by violent collision with each other on a sea-beach. This final polishing points to erosion by sand-laden wind after they had been rolled into shape. The rounding of sand grains has been at various times fully discussed, and it is generally admitted that this rounding and polishing is due to attrition in open air rather than under water. These rounded or " millet-seed " grains are more common in the soft beds, such as the Upper or Lower Bunter, than in the harder, but this does not necessitate a different method of distribution, for many of the angular grains are such by reason of a secondary deposit of silica having crystallised upon the surface of a rounded grain. The Æolian action is still more marked in the Lower Keuper sandstones, so that to begin with we have a large area of shifting sands with continual attrition between the constituent parts of all sizes, whether sand grains or pebbles.

This continued attrition would produce an enormous amount of very finely comminuted quartz and other minerals represented in the sand and pebbles. The fine dust thus produced would, when once caught up by the wind, remain suspended in the atmosphere, would readily be transported great distances, and it is of just such fine particles that the Marls are largely composed.

Messrs. Dickson and Holland* have shown that the inter-bedded marls in the Lower Keuper in which the original footprints, found at Storeton and elsewhere, were made are also composed largely of these fine particles of

* Proc. L'pool Geol. Soc., Vol. vii., p. 448.

quartz. I have elsewhere attributed these beds to temporary accumulations of water, in which the finer particles were deposited. At the time I mentioned this, I had in mind the carrying down of the fine detritus by the small rivulets made by occasional rain, but a suggestion was made to me by Mr. Lomas, to whom alone the idea is due, that the Keuper marls as well as the sandstones may be due to wind-action, and I have been led to work out in my mind how this might take place. For the idea Mr. Lomas must have all the credit, for the many flaws in my working it out I must take all the blame.

The heavy rain itself would clear the atmosphere of the dust locally, falling as muddy rain, as recorded by Colonel Tanner quoted by Mr. Hewitt in his paper. The rain having ceased, these fine particles would again fill the air and continue their journey to windward; those that touched the ground would again rise and continue their journey. Those in Central Asia continuing their journey as Baron Von Richthofen says, till they rest on the plains of China, form there the loess.

Those that touched the water would, however, be retained and gradually sink to the bottom. Supposing a portion of the country to be occupied by a large sheet of water, whether salt or fresh does not matter, there the onward movement of the stream of dust is arrested.

Such is a rough outline of my idea of the formation of the Red Marls.

The wind-borne dust will account for the fineness of the deposit, but does not imply that there was no water-borne material. There are few absolutely rainless regions at present, and where there is rain there will, at any rate, be temporary streams and pools.

The frequent occurrence of ripple marks, footprints, and other things indicating shallow water or a more or less moist surface would point decidedly to a shallow sheet

of water of varying extent, with a land surface at no great distance which supplied food for the animals and also the fragments of plants that are often met with.

In the traces of reptilian life there is nothing pointing positively to aquatic habits except one footprint with a webbed foot, the other prints from the same locality show no trace whatever of webbing. Some of the sandstones contain fishes, and both sandstones and marls show Estheria minuta and perhaps other species of that genus.

The fishes belong principally to the genus *Semionotus*, and a few teeth and spines of other genera are recorded. Recent Estheria are brackish water crustaceans, and possess the power of retaining their vitality when buried in the dried-up mud. All this points to shallow water. We also have the very frequent occurrence of pseudomorphs of salt occasionally associated with footprints and with fragmentary plant remains. But, on the other hand, we have a bed of salt 100 feet thick, apparently a continuous deposit, which it is difficult to suppose was formed in shallow water, and we have occasionally beds of fairly pure gypsum 20 and 30 feet thick.

This creates a difficulty with regard to the deposition of the other material. If the other material were deposited in shallow water, one can hardly imagine a thick bed of salt like this associated with it. A thick bed of anything may be formed in a sheet of water that always remains shallow if the water occupies a gradually subsiding area, an area whose subsidence is mainly consequent on the weight of sediment accumulated, but a bed of salt of that thickness under those circumstances must have taken a very long time to form, and during that time the material of the marl must have been accumulating, and you would have a bed of mingled salt and marl, as is the case at other horizons—whereas this bed is comparatively pure.

The presence of the salt beds in the Upper Keuper of

Cheshire and the Midlands has attracted attention from the very early days of Geology. Prof. J. Playfair, "Illustrations of the Huttonian Theory," edition 1802, in Section 33, page 27, says:—"The mere precipitation of "salt would, as Dr. Hutton observes, form only an "assemblage of loose crystals at the bottom of the sea with- "out solidity or cohesion, and to convert such a mass into "a firm and solid rock would require the application of "such heat as was able to reduce it to fusion." Playfair mentioned this as showing evidence of the action of heat in assisting in the formation of the earth's crust.

The earliest general statement of a theory of their origin that I have come across was contained in the first vol. Trans. Geological Society, 1811, in a "Sketch of the Natural History of the Cheshire Rock Salt District," by Henry Holland, Esq. In it he says:—"Though it must "be acknowledged that there are some difficulties con- "nected with the supposition, little doubt can exist of the "general fact that the beds of this mineral have been "formed by deposition from the water of the sea." He then goes on to say:—"To account for the great "deposition of salt in the lower parts of this basin, it is "necessary to suppose that some barrier must have been "afterwards interposed to prevent the free communication "of the waters of the sea with those collected, and the "general course of the streams, the position of the beds "of rock salt, and the contractions of the valley of the "Weaver which appear below Northwich at Anderton "and Frodsham, point out with some distinctness the "place where these obstructions may probably have "occurred." He further supposes that the obstruction continued after the salt had ceased to be deposited, but that the clay that had hitherto been deposited with the salt became the principal deposit mixed with a little salt; that when these had reached a thickness of 10 or 20

yards the barrier was so far removed as to re-admit a fresh body of sea water, and the process was repeated. Then he says, "With the exception of sulphate of soda, the "salts that occur are found with minerals of soda in the "sea." The great objection he saw to this theory was "the absence of marine exuviæ, either in the rock salt or "in the adjacent strata of clay; he sees "no reason "for the action of subterraneous or internal heat in the "formation of rock salt."

I have quoted from this paper at length, because in it Sir Henry Holland seems to have given nearly a century ago, clearly expressed and illustrated, very much the theory that apparently still holds the field, though, of course, in many details an advance has been made. The older geologists did not seem to grasp the idea of changes of such enormous magnitude in the physical geography of the country or of the vast lapse of time which is now so familiar to us, hence his idea of the sea having entered through the gap in the hills at Frodsham.

The objection from the absence of marine exuviæ is not removed, though its force is lessened. We have traces of animal life coeval with the salt in the footprints of animals side by side with salt pseudomorphs, but one cannot pronounce positively for or against their marine habits.

Mr. Ormerod thought there was some connection between the beds of rock salt and the dislocation of the strata as though it were due to some subterranean force—but, so far, the sea theory seems the more generally accepted, the more so as the investigations of the chemist lend it some support, and find the salts contained in the saliferous marls are those found in sea water. I do not feel quite sure that the salt and gypsum do invariably occupy the relative positions or are in the proportions theory would assign to them. The gypsum would be

deposited long before sufficient evaporation had taken place to throw down the chloride of sodium, and we do not know how much salt has been removed.

The extent of the beds of salt is not yet accurately determined, but there is little doubt that they are not continuous over the whole area; nor is their position in the series very certain, the difficulty of correlating the strata in the absence of fossils being very great. But, even if we had more accurate information on these points, we should not know what they were as originally laid down. Salt springs all over the district have been running continuously we know for some 2,000 years or thereabouts, and for a period of unknown duration previously, and must have removed a very large quantity, but, however that may be, we know enough to see that the total thickness of salt would require for its formation a greater depth of water than could with any probability be supposed to have at any one time been present in the limited area occupied by the saliferous marls supposing them to have originally extended from the Charnwood Forest range to the North of Ireland, which seems probable, and from the range of ancient rocks, now hidden by the chalk, &c., in the South, to the North of England. The inland sea would have been of comparatively small area, even at its greatest extent. As its waters evaporated, the gypsum being first thrown down would be disseminated over a considerable area, as we find it to be the case,* but the water would be very largely reduced in quantity before salt was formed, and it would only cover a small area in the deepest part of the original sea. During this process of dessication, however, the mechanical deposits would have been forming, and we might expect to find the richest beds of rock salt near the top of the series.

* The amount of gypsum would appear to bear a greater proportion to the rock salt than exists in sea water.

So much for the possibility of the salt having been the result of the evaporation of a great body of sea water whose connection with the open ocean had been closed. We have seen that it would be during the later stages of evaporation that the salt would be deposited.

Now, although we do not find beds of salt in the Waterstones or the lower strata of the Red Marls, we do find pseudomorphs of rock salt there, and occasionally I have seen salt pseudomorphs in the Lower Keuper itself. In beds in the Red Marl, which are evidently formed in shallow water, they are numerous, sometimes associated, as I said before, with the footprints of vertebrates and with plant remains. Of course, the vegetable fragments, for they are never more than fragments, might easily sink through some depth of water, but the footprints of an animal could only be made on a surface above the water level, or but a very slight depth below it. This indication of salt crystals in shallow water was explained in one of the early papers on this subject by Mr. Strickland.* He suggests that the surface was originally a salt marsh overflowed by the sea at spring tides, and, the water evaporating, left a deposit of salt crystals before the next spring tide. This dissolved the salt crystals, leaving cubical cavities in the mud into which the silt with which it was charged was deposited. The under side of the new layer exhibiting when it became consolidated the pseudomorphs as we now have them. He further observed that they are also formed on the upper side, and he suggests that the lower layer was forced up by pressure into the hollow formed by the solution of the original crystals after the deposition of the upper layer. This is not an altogether satisfactory explanation.

This salt marsh and tidal overflow quite accounts for the presence of the pseudomorphs and very

* Quart. Jour. Geol. Soc., Vol. ix., p. 5.

thin beds of salt. It is quite possible, too, that only the highest tides of the year at the equinoxes might overflow some slight barrier and fill a local depression with a greater depth of water which the longer period of six months might suffice to evaporate, and thus a deeper deposit of salt would be formed. Such conditions are not very probable to any great extent, though the Run of Cutch is an example at the present day. Also we are not very certain as to the action of the tides in Triassic times, the probabilities are that they had a greater rise and fall if they differed at all appreciably from the present time. We should then have layers of fine sediment and beds of salt alternating, but I can hardly suppose the individual beds of salt to have been of any great thickness, and the layers of salt would not have been continuous vertically so as to form a layer such as we find at Northwich. We must then fall back on the supposition that the lakes were cut off from the sea for a considerable period whilst deposition, evaporation and depression took place. After a while the connection was again opened, a fresh influx of sea water took place and further deposition of salt was arrested, a quantity of that already deposited being removed unless the connection was maintained for a very brief period only, and then the operation was repeated.

These are the different forms in which the sea action may take place. Each of them has had its advocates, but I cannot see how either of them by itself can have produced the formation as we find it. All of them are necessary to explain the varieties of phenomena presented, but even then we still find many things unexplained, and the more the beds themselves are studied the greater the difficulties that arise in accepting the marine theory.

Again, there is the suggestion that rivers slightly saline may through long periods have emptied themselves

into the lake, the loss by evaporation exceeding the amount of water brought down. The question then arises whence did the rivers obtain their salt, and this requires more investigation than has yet been recorded.

The question of the history of the salt beds seems to me to be still an open one, none of the explanations usually given being satisfactory.

As regards the deposits other than salt, an aqueous agency is not absolutely necessary, though extremely probable. The fine beds of marl might be the wind-drifted *debris* of the adjoining desert, but how they could be brought to rest at one place otherwise than by contact with water I could not explain. The water need not be any great depth, but it must be there to arrest the driving sand and dust.

That an immense amount of fine dust is formed by the attrition of the dry grains of sand is, I think, certain, and that a haze of such fine dust exists over the great arid districts of Central Asia is a fact mentioned by trustworthy explorers.

The wind that heaps up the sand into sand dunes will carry the dust to much greater distances, for such an obstacle as would arrest the drifting sand would not affect the finer particles which can move at a higher level, but when these particles come in contact with water their career is arrested—they slowly sink to the bottom, and, being covered by countless myriads of their brother particles, are consolidated into rock as we now find them.

In case my theory is correct, the chemical composition of the marls should be similar to that of the underlying sandstones, and this can only be determined by the careful analysis of a number of samples of each. My friend, Mr. Boothman Roberts, has very kindly made a preliminary examination of a few samples, and I hope that before long we may have a communication from him on the subject.

The average size of the grains, he tells me, appears to be only $\frac{1}{5000}$ of an inch (or ·005 mm.) in diameter. Such finely-divided material would not only be readily carried by wind to great distances, but it would be more readily susceptible of those chemical changes that Messrs. Dickson and Holland have suggested as necessary to transform mere mud into a true clay.*

I have referred only to the Trias of the English Midlands as the only district of which I have any personal knowledge, but they would seem to have been but a small portion of a great desert tract extending across Europe in early Secondary times. Then at a later period we have similar conditions existing in Asia, and continuing to the present.

I regret that I have not been able to refer to the Report of the Expedition sent out by the Carnegie Institute of Washington to Eastern Persia and Turkestan, and just issued; but a short time since I came across a paper read before the Geological Society in 1854 by W. Kenneth Loftus, Esq., F.G.S., on "The Geology of portions of the Turco-Persian Frontier and the Districts adjoining."† It is a lengthy and thoroughly scientific account of the country through which he passed, and is of very great interest. He describes and gives sections of a series of marls and sandstones and beds of gypsum of Tertiary age which would, apart from their organic remains and their position above Secondary rocks, quite answer to our Upper Trias; further, they also resemble the present surface accumulations of the district. He also mentions slabs of sandstone bearing footprints similar to those of our English Trias, except that the prints are those of one of the larger Carnivora. One of these is in the British Museum: Natural History,‡ and

* "On the formation of Clay," Proc. L'pool Geol. Soc., Vol. vii., p. 108.
† Quart. Jour. Geol. Soc., Vol. xi., p. 252.
‡ No. 32,409.

its resemblance to our Triassic slabs, near which it is placed, is very striking. I refer to this as illustrating the identity of the operations of Nature at various periods of the earth's history.

The secrets of the Trias are only to be discovered by the study of the various desert regions of the world existing as they do in each of the continents.

Since the date of Mr. Hewitt's paper, before referred to, a vast amount of exploration has been carried out, and if the results, as far as they relate to this subject, could be brought together, it would help us greatly.

I also hope that the geologists of the British Association will bring home with them, as the result of their observations of the South African Triassic rocks and the desert districts at present existing there, much that will help to clear up the difficulties we have been considering this evening.

THE COLORADO CANYON AND ITS LESSONS,

By W. M. Davis, Harvard University.

The Colorado Canyon in the plateaux of Northern Arizona was first made vaguely known through the reports of Spanish explorers from Mexico over a century ago, first properly described by Newberry, who entered it from below fifty years ago, and by Powell who ten years later made an adventurous journey down the river in boats, and first monographed by Dutton and Holmes in a famous report published by the United States Geological Survey about 1880. It can now be comfortably reached in four days by rail from New York, and it is annually visited by thousands of travellers. Naturally enough, this profound chasm was first popularly explained as the result of a great fracture in the earth's crust, but nothing could be further from the truth; it is simply an unusually deep valley, the work of normal processes of wearing and weathering such as are in operation all over the lands. It is true that the aridity of the region has contributed to the relative narrowness of the Canyon, but the chief reason for its narrowness is that time enough has not elapsed since the plateaux were elevated and the erosion of the Canyon was begun for it to have been greatly widened.

An observer standing on the rim of the Canyon, and looking down into its depths, may well be excused for thinking that, if the Canyon be really the work of the ordinary agencies now in operation, the time required for its erosion must have been a large share of the earth's age; but closer study will show that the very opposite is the truth. The marvellous section of the earth's crust,

disclosed in the Canyon walls, contains abundant evidence, needing only to be looked at to be seen, needing only to be considered to be understood, to the effect that the erosion of the Canyon has taken place in a comparatively short chapter of time at the end of a great series of much longer records. It is the reading of these records that gives us the real lesson of the Canyon.

Figure 1 gives a rough section of the structures shown in the Canyon walls. The plateau is thus found to be built of a heavy series of horizontal strata, T T, W W, Y Y, about 4,000 feet thick, ranging from Silurian to Carboniferous, and lying unconformably on a comparatively even floor, A B D. Below this floor there are two formations to be distinguished—a series of slanting strata, C B D, dipping eastward and measuring in all about 10,000 feet in thickness; and a mass of crystalline rocks, A B C, whose structure has not yet been deciphered. The river, R R, as seen in side view, and the Canyon, as drawn in cross profile, may thus be apprehended in their geological relations. Let us now step rapidly backward through the various chapters of time here recorded.

Before the Canyon was eroded, the rock layers of the plateau stretched across its space, as indicated by the dotted lines. Before the horizontal layers of the plateau were deposited, the horizontal floor, A B C, must have been prepared, and this preparation can have been accomplished only through the removal by erosion of the once superincumbent masses shown by the dotted lines of figure 2. Previous to this chapter of erosion, the now slanting layers and their crystalline foundation must have been bodily tilted into the attitude shown in figure 2 from the original attitude shown in figure 3. Here again, before deposition of the stratified series, the crystalline floor, E B C, must have been prepared, and this can have been done only by a huge amount of erosion, by which the

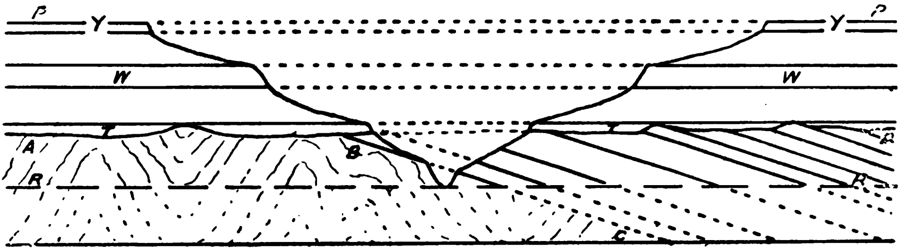

Fig. 1.

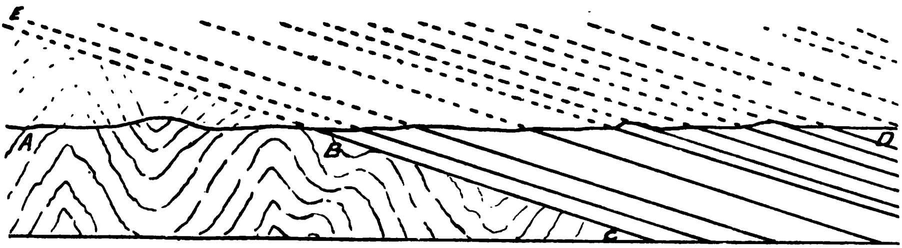

Fig. 2.

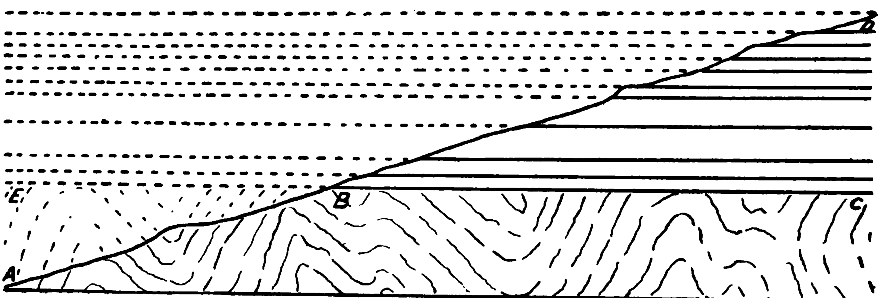

Fig 3

once superincumbent mountains, suitable to the greatly deformed and metamorphosed structures of the crystallines, were removed. The making and the deformation of the crystallines doubtless occupied a long series of time chapters, but these are still to be deciphered. Now the history of the mass may be reviewed in normal order, and the duration of the several chapters may be compared with that in which the Canyon has been eroded.

The production of the even crystalline floor, E B C, figure 3, must have required a vastly longer time than the erosion of the Canyon, for the complete obliteration of a mountain system is a greater work than the cutting of a valley. The deposition of the next overlying series in great thickness over a large area must have required a vastly longer time than the erosion of the Canyon, for the deposition of that series involved the erosion of a corresponding amount of material elsewhere, and this volume was immensely greater than that of the Canyon. The tilting and erosion indicated by the change from figure 3 to figure 2 must have required a vastly longer time than the erosion of the Canyon, for the erosion by which the floor, A B D, was prepared involved the removal of a vastly greater volume of material than has been taken out of the Canyon. The deposition of the horizontal series in figure 1, stretching far and wide over the plateaux, must have required a vastly longer time than the erosion of the Canyon, for the deposition of that series involved the erosion of an equal amount of material elsewhere, and that erosion was vastly greater than that of the Canyon. Not only so; some fifty miles north of the Canyon, near the boundary between Arizona and Utah, is a number of huge terraces formed on the edges of a series of resistant strata, that once stretched far over the plateau country. The deposition and the extensive removal of these strata each required a vastly longer time than the erosion

of the Canyon. Thus we find evidence in the Canyon walls, and on the plateau not far north, of six chapters of past time, to say nothing of the crystallines, each of which greatly exceeded the length of the Canyon-cutting chapter. Thus interpreted, the erosion of the Canyon takes its proper place: not a great event in the history of the earth, but a supplement to a long series of much greater events. The Canyon, deep as it is, is only a young feature of the earth's surface. It reminds one of the country in which it is found: young and vast, even precocious, but not yet venerable.

THE PLEISTOCENE CLAYS AND SANDS OF THE ISLE OF MAN.

By T. MELLARD READE, F.G.S., F.R.I.B.A., A.M.I.C.E., and JOSEPH WRIGHT, F.G.S.

The drift of the northern plain of the Isle of Man is well known through the labours of Cummings, Horne, Kendal, Lamplugh and others. It is doubtful if any known drift sections in Britain, excepting those at Cromer on the east coast, surpass those to be found at Cranstall Cliffs for interest and magnitude.

Though the erratic rocks that occur in the sands and clays have been observed and enumerated, and other features usually looked for by glacialists investigated, we are not aware of any systematic microscopic examination having been carried out.*

To supply this want we have made a typical collection of sands and clays, thirteen in all, the microscopical examination of which it is the object of this paper to record. The specimens were taken in the year 1900.

Before going into the details of our labours it is necessary to say that no particular order or sequence was observed in the collection of the specimens. We simply from day to day examined conspicuous exposures, noted the observations, and collected characteristic variations of the beds of clays and sands.

* In the autumn of 1900 one of us, when in the Isle of Man, went to Shellag to see the Pleistocene clays and sands, which are well exposed in the cliffs along the shore about four miles north of Ramsey. As these deposits had not previously been examined for Microzoa, nine pounds weight of the clay (not the sand), was brought away for examination. A list of the foraminifera obtained is given in the Journal of the Isle of Man Nat. Hist. and Ant. Soc., Vol. iii., p. 627, 1902. This is the only reference, as far as we know, to the presence of foraminifera in the Isle of Man drift, other than what is contained in this paper.

INORGANIC CONSTITUENTS OF THE CLAYS AND SANDS.

As the mechanical analyses show that the clays and sands though lithologically different are composed mainly of similar minerals varying only in the proportions in which they occur, it will be sufficient to give a general sketch of their characteristics and composition.

Firstly, there is a striking resemblance in the residual washings to those observed from the South-west Lancashire low-level marine boulder clay.* The fine washings that flow away are *mud*—fine mineral particles mixed with clay, and according to the preponderance of actual clay are known roughly as clays or sands. In some cases the clay is in sufficient force to make the boulder clay fit for the manufacture of bricks, though the presence of fragments of limestone often spoils them for that purpose. Some of these clays in the Isle of Man are used for brickmaking.

The sand whether coarse or fine is, we may say, generally much rounded, and in some cases the grains are highly polished, as if recently subjected to attrition. It is remarkable how this applies to even the finest quartzose sands, such as Nos. 2, 7 and 12. The finest quartzose material is what has been called "flour of rock," and consists of extremely minute splintery fragments of quartz.

That the sand mostly contains a considerable proportion of calcareous matter in the form of grains is evident on applying acid on a slide containing a little sand and examining it with a low power under the microscope. Specimen No. 12, from West Craig Brickworks, is remarkable as containing practically no gravel or boulders and being of very fine texture. No. 7, north

* "Marine" is used to differentiate it from clays that do not contain marine organisms.

of the Mooragh, is a fine textured bed of clay intercalated in the drift. However fine the clay may be the mineral remainder after washing is characteristically the same as that of the coarsest.

A distinguishing feature in the clays and sands is the abundant presence of shell fragments, and these are often extremely small and well rounded.

The mineral grains other than quartz are mainly similar in character to the boulders in the drift. These boulders appear to have come from the north, the west, and from the east. Even a large boulder of Shap granite was discovered by the Rev. S. N. Harrison, of which we hold a characteristic fragment, and others are recorded by Mr. Lamplugh in his official Memoir of the Geology of the Isle of Man.

Those who desire to study the drift from the point of view of a pronounced land-ice theorist cannot do better than read this memoir. The observations are detailed and full.

Our object not being of a controversial nature we pass by the bearing of these complex facts without discussion. They have been interpreted differently even by those whose observations are in agreement, and it is doubtful if anything could be added which would influence the rival views either one way or another.

The microscopical investigation has shown the presence of foraminifera in nearly all the drift beds examined, whether clay or sand. In some cases they occur in great profusion, and, as will be shown, they are present in the greatest numbers in the finer textured specimens. Interpret these facts as we may, the almost universal presence of foraminifera in the drift of the northern plain is a fact of considerable significance, and we venture to think well worth recording.

The following is a detailed list of species:—

No. 1 Cranstall Cliffs, Specimen A (p. 113). Weight of clay, 26 oz. troy; after washing, fine, 14 oz., coarse, 2·4 oz. Foraminifera plentiful (218 specimens).

FORAMINIFERA.

Miliolina subrotunda (Montag.).—Very rare.
Verneuilina spinulosa, Rss.—Very rare.
Bolivina punctata, d'Orb.—One specimen.
B. plicata, d'Orb.—Very common.
B. dilatata, Rss.—Rare.
Cassidulina crassa, d'Orb.—Very common.
Lagena marginata, W. & B.—Common.
L. lucida (Will.)—One specimen.
L. fimbriata, Brady.—One specimen.
Uvigerina angulosa, Will.—Very rare.
Globigerina bulloides, d'Orb.—Very common.
G. cretacea, d'Orb.—One specimen.
Orbulina universa, d'Orb.—Frequent.
Discorbina rosacea (d'Orb.)—One specimen.
D. globularis (d'Orb.)—One specimen.
D. obtusa (d'Orb.)—Common.
Nonionina depressula (W. & J.)—Very common.
Polystomella striato-punctata (F. & M.)—One specimen.

The most abundant forms, not only here, but also in the greater part of the other gatherings, are *Bolivina plicata*, *Cassidulina crassa*, *Globigerina bulloides*, and *Nonionina depressula*. The only species of interest met with was *Lagena fimbriata*.

No. 2. Cranstall Cliffs, Specimen B (p. 112). Weight of clay, 24·2 oz. troy; after washing fine, 19·9 oz., coarse, ·3 oz. Foraminifera plentiful (145 specimens).

FORAMINIFERA.

Miliolina subrotunda (Montag.)—One specimen.
Bolivina plicata, d'Orb.—Frequent.

B. dilatata, Rss.—One specimen.
Cassidulina crassa, d'Orb.—Frequent.
Lagena globosa (Montag.)—One specimen.
L. lineata (Will.)—Rare.
L. sulcata (W. & J.)—Rare.
L. Williamsoni (Alcock)—Rare.
L. squamosa (Montag.)—Rare.
L. hexagona (Will.)—Very rare.
L. marginata, W. & B.—Very rare.
L. lucida (Will.)—One specimen.
L. fimbriata, Brady—One specimen.
Uvigerina angulosa, Will.—One specimen.
Globigerina bulloides, d'Orb.—Common.
G. cretacea, d'Orb.—One specimen.
Orbulina universa, d'Orb.—Rare.
Discorbina globularis (d'Orb.)—One specimen.
D. obtusa (d'Orb.)—Rare.
Nonionina depressula (W. & J.)—Rare.

In this gathering the Lagenæ were somewhat numerous and well grown, the other foraminifera being very minute in size. Only a few specimens were obtained of *Nonionina depressula*, a form usually more or less abundant in Pleistocene deposits.

No. 3. Shellag Brow, Specimen C (p. 110). Weight of sand, 37·9 oz. troy; after washing, fine, 21·8 oz., coarse, 14·7 oz. Foraminifera none.

No. 4. Shellag Brow, Specimen D (p. 111). Weight of sand, 33·8 oz. troy; after washing, fine, 29·2 oz., coarse, 2·3 oz. Foraminifera frequent (75 specimens).

Foraminifera.

Bolivina plicata, d'Orb.—Frequent.
B. dilatata, Rss.—One specimen.
Cassidulina crassa, d'Orb.—Rare.
Lagena Williamsoni (Alcock)—One specimen.

L. squamosa (Montag.)—One specimen.
L. hexagona (Will.)—One specimen.
L. marginata, W. & B.—Rare.
Globigerina bulloides, d'Orb.—Frequent.
Uvigerina angulosa, Will.—Very rare.
Discorbina rosacea (d'Orb.)—Very rare.
D. obtusa (d'Orb.)—Rare.
Pulvinulina Karsteni (Rss.)—One specimen.
P. nitidula, Chaster.—One specimen.
Nonionina depressula (W. & J.)—Rare.

No. 5. Cliffs beyond (north of) Dog Mills (talus sand), Specimem E (p. 111). Weight of sand, 33·4 oz. troy; after washing, fine, 32 oz., coarse, ·3 oz., a few shell fragments. Foraminifera frequent (64 specimens).

FORAMINIFERA.

Miliolina sp.—One specimen.
Verneuilina spinulosa, Rss.—One specimen.
Bolivina textilarioides, Rss.—One specimen.
B. plicata, d'Orb.—One specimen.
B. dilatata, Rss.—Very rare.
Cassidulina crassa, d'Orb.—Frequent.
Lagena lucida (Will.)—One specimen.
Globigerina bulloides, d'Orb.—Frequent.
G. cretacea, d'Orb.—Very rare.
Orbulina universa, d'Orb.—Very rare.
Discorbina obtusa (d'Orb.)—Rare.
Nonionina depressula (W. & J.)—Common.
Polystomella striato-punctata (F. & M.)—Very rare.
P. macella (F. & M.)—One specimen.

No. 6. Cliffs just South of Dog Mills (talus). Weight of sand 29 oz. troy; after washing, fine, 18·2 oz., coarse, ·2 oz., sand very fine with shell fragments. Foraminifera in great profusion (1,350 specimens).

Foraminifera.

Miliolina seminulum (Linné)—Frequent.
M. subrotunda (Montag.)—Common.
Cornuspira involvens, Rss.—One specimen.
Textularia globulosa, Ehr.—Frequent.
Verneuilina pygmæa (Egger)—Frequent.
Bulimina pupoides, d'Orb.—Rare.
B. marginata, d'Orb.—One poor specimen.
B. fusiformis, Will.—Very rare.
B. elegantissima, d'Orb.—Very rare.
Bolivina punctata, d'Orb.—Rare.
B. plicata, d'Orb.—Very common.
B. textilarioides, Rss.—One specimen.
B. dilatata, Rss.—Very rare.
B. serrata (Chapman)—One specimen.
Cassidulina crassa, d'Orb.—Very common.
Lagena lineata (Will.)—Very rare.
L. costata (Will.)—Very rare.
L, sulcata (W. & J.)—Very rare.
L. Williamsoni (Alcock)—One specimen.
L. squamosa (Montag.)—One specimen.
L. reticulata (Macgill.)—One specimen.
L. marginata, W. & B.—Rare.
L. lucida (Will.)—Rare.
L. Orbignyana (Seg.)—One specimen.
L. fimbriata, Brady—Rare.
Polymorphina lanceolata, Rss.—One large broken specimen.
Uvigerina angulosa, Will.—Very rare.
Globigerina bulloides, d'Orb.—Most abundant.
G. cretacea, d'Orb.—Frequent.
Orbulina universa, d'Orb.—Common.
Discorbina globularis (d'Orb.)—Very rare.
D. rosacea (d'Orb.)—Rare.
D. obtusa (d'Orb.)—Common.
D. minutissima, Chaster—Very rare.
Pulvinulina auricula (F. & M.) var.—One specimen.

P. Karsteni, Rss.—Frequent.
P. nitidula, Chaster—Very rare.
Nonionina depressula (W. & J.)—In great profusion.
N. stelligera, d'Orb.—One specimen.
Polystomella striato-punctata (F. & M.)—Frequent.

This very fine sand contained foraminifera in great profusion, *Nonionina depressula* and *Globigerina bulloides* being especially abundant. Of the former 650 specimens were found, and of the latter 225. The most noteworthy forms are *Cornuspira involvens*, *Verneuilina pygmæa*, *Bolivina serrata*, *Lagena fimbriata*, *Discorbina minutissima*, *Pulvinulina nitidula*, and *P. Karsteni*.

No. 7. Marl Cliffs just north of the Mooragh, near White Cottage, south of last specimen (6). Weight of clay, 27·4 oz. troy; after washing fine, ·9 oz., coarse, none. Foraminifera most abundant (about 1,100 specimens).

Foraminifera.

Miliolina seminulum (Linné)—Frequent.
M. oblonga (Montag.)—One specimen.
M. subrotunda (Montag.)—Rather rare.
Cornuspira involvens, Rss.—Very rare.
Textularia globulosa, Ehr.—Very rare.
Bulimina pupoides, d'Orb.—One specimen.
B. fusiformis, Will.—Rather rare.
B. elegantissima, d'Orb.—Very rare.
Bolivina plicata, d'Orb.—Very common.
B. textilarioides, Rss.—Very rare.
Cassidulina crassa, d'Orb.—Very common.
Lagena lineata (Will.)—One specimen.
L. marginata, W. & B.—Frequent.
L. lucida (Will.)—Very rare.
L. fimbriata, Brady—One specimen.
Nodosaria pyrula, d'Orb.—One specimen.

Polymorphina lactea, var. oblonga, Will.—One specimen.
P. lanceolata, Rss.—One specimen.
Uvigerina angulosa, Will.—Very rare,
Globigerina bulloides, d'Orb.—Very common.
Orbulina universa, d'Orb.—Frequent.
Patellina corrugata, Will.—One specimen.
Pullenia sphæroides, d'Orb.—One specimen.
Discorbina rosacea (d'Orb.)—Rather rare.
D. obtusa (d'Orb.)—Rather rare.
D. minutissima, Chaster—Very rare.
D. tuberculata, B. & W.—One specimen.
Pulvinulina auricula (F. & M.) var.—Rather rare.
P. Karsteni (Rss.)—Rather rare.
Nonionina depressula (W. & J.)—Most abundant.
Polystomella striato-punctata (F. & M.)—Very rare.

This material was very similar to the last sample, foraminifera occurring in great profusion, and *Nonionina depressula* and *Globigerina bulloides* being very abundant, the former numbering about 600 specimens, and the latter about 200. The following are amongst the rarer forms:—*Cornuspira involvens, Lagena fimbriata, Nodosaria pyrula, Patellina corrugata, Pullenia sphæroides, Discorbina tuberculata, D. minutissima* and *Pulvinulina Karsteni.*

No. 8. Red clay in drift, Ballure Glen, sample taken at A (p. 106). Weight of clay, 23·7 oz. troy; after washing, fine, 4·4 oz., coarse, ·8 oz. One specimen of *Cassidulina crassa.*

No. 9. Boulder Clay, Ancient Sea Cliff near Smeale (p. 102). Weight of clay, 24·5 oz. troy; after washing, fine, 16·1 oz., coarse, 2 oz. Foraminifera very rare.

FORAMINIFERA.

Bolivina sp. —One specimen.
Globigerina bulloides, d'Orb.—One specimen.

No. 10. Marl pit in Ancient Sea Cliff two miles South-west of Point of Ayre (p. 125). Weight of clay, 31·4 oz. troy; after washing, fine, 16·3 oz., coarse, 1·4 oz. Foraminifera plentiful (125 specimens).

FORAMINIFERA.

Textularia globulosa, Ehr.—One specimen.
Verneuilina pygmæa (Egger)—Very rare.
Bolivina punctata, d'Orb.—One specimen.
B. plicata, d'Orb.—Rare.
Cassidulina crassa, d'Orb.—Rare.
Lagena Williamsoni (Alcock)—One specimen.
Uvigerina angulosa, Will.—One specimen.
Globigerina bulloides, d'Orb.—Frequent.
Orbulina universa, d'Orb.—One specimen.
Discorbina rosacea (d'Orb.) ?—One specimen.
D. obtusa (d'Orb.)—Rare.
Truncatulina refulgens (Montf.)—One specimen.
Nonionina depressula (W. & J.)—Common.

No. 11. Port Lewaique Brick Works (p. 109). Weight of clay, 27·3 oz. troy; after washing, fine, 11·9 oz., coarse, 1·8 oz. Foraminifera in great profusion (670 specimens).

FORAMINIFERA.

Miliolina seminulum (Linné)—Frequent.
M. subrotunda (Montag.)—One specimen.
Textularia globulosa, Ehr.—Very rare.
Verneuilina pygmæa (Egger)—One specimen.
Bulimina fusiformis, Will.—One specimen.
Bolivina punctata, d'Orb.—One specimen.
B. plicata, d'Orb.—Common.
B. dilatata, Rss.—Very rare.
Cassidulina crassa, d'Orb.—Common.
Lagena lineata (Will.)—One specimen.
L. marginata, W. & B.—Very rare.

L. lucida (Will.)—Very rare.
Cristellaria crepidula (F. & M.)—One specimen.
Uvigerina angulosa, Will.—One specimen.
Globigerina bulloides, d'Orb.—Common.
Orbulina universa, d'Orb.—Frequent.
Discorbina rosacea (d'Orb.)—One specimen.
D. obtusa (d'Orb.)—very rare.
Nonionina depressula (W. & J.)—Most abundant.

This clay was very dirty, with vegetable matter, and was probably deposited in quiet water near land. There were 500 specimens of *Nonionina depressula*, the other foraminifera numbering only 170.

No. 12. West Craig Brick Works (p. 100). Weight of clay, 21·4 oz. troy; after washing, fine, 9·4 oz., coarse, 1 oz. Foraminifera in great profusion (738 specimens).

FORAMINIFERA.

Bolivina plicata, d'Orb.—One specimen.
Cassidulina crassa, d'Orb.—Very rare.
Lagena marginata, W. & B.—One specimen.
Globigerina bulloides, d'Orb.—Very rare.
Nonionina depressula (W. & J.)—In great profusion.

In this gathering the difference in numbers between *Nonionina depressula* and the other foraminifera is even still more remarkable than in the last sample, 730 specimens of this species being obtained, whilst the other foraminifera numbered only eight.

No. 13. Sea Cliff just north of Glen Wyllin, Kirkmichael, specimen at E in Section (p. 137). Weight of clay, 24 oz. troy; after washing, fine, 9·4 oz., coarse, 1 oz. Shell fragments frequent. Foraminifera in great profusion (1,612 specimens).

Foraminifera.

Miliolina seminulum (Linné)—Rare.
M. subrotunda (Montag.)—Frequent.
Textularia globulosa, Ehr.—Very rare.
Verneuilina pygmæa (Egger)—Very rare.
Bulimina pupoides, d'Orb.—Very rare.
B. fusiformis, Will.—Very rare.
B. elegantissima, d'Orb.—Very rare.
Bolivina punctata, d'Orb.—Frequent.
B. plicata, d'Orb.—Very common.
B. dilatata, Rss.—Very rare.
Cassidulina lævigata, d'Orb.—Very rare.
C. crassa, d'Orb.—Very common.
Lagena sulcata (W. & J.)—Very rare.
L. marginata, W. & B.—Very rare.
L. lævigata (Rss.)—Very rare.
L. Orbignyana (Seg.)—Very rare.
Nodosaria pyrula, d'Orb.—Very rare.
N. calomorpha, Rss.—One segment only.
Polymorphina lanceolata, Rss.—Very rare.
Uvigerina angulosa, Will.—Very rare.
Globigerina bulloides, d'Orb.—Common.
G. cretacea, d'Orb.—Rare.
Orbulina universa, d'Orb.—Rather common.
Patellina corrugata, Will.—Very rare.
Discorbina globularis (d'Orb.)—Very rare.
D. rosacea (d'Orb.)—Frequent.
D. orbicularis (Terq.)—One specimen.
D. obtusa (d'Orb.)—Frequent.
D. minutissima, Chaster,—Very rare.
Pulvinulina auricula (F. & M.)—Very rare.
P. Karsteni (Rss.)—Rare.
Rotalia orbicularis, d'Orb. ?—One specimen.
Nonionina depressula (W. & J.)—In great profusion.
Polystomella striato-punctata (F. & M.)—Very rare.
P. macella (F. & M.)—One specimen.
P. arctica, P. & J. ?—Very rare.

This material yielded foraminifera in the greatest profusion, about 1,000 of the specimens being referable to *Nonionina depressula*. The following are amongst the rarer species:—*Verneuilina pygmæa, Bulimina elegantissima, Cassidulina lævigata, Patellina corrugata, Discorbina orbicularis,* and *D. minutissima.*

General Observations.

The Pleistocene clays and sands from the Isle of Man are very varied in their composition; some are composed of clay, more or less sandy or stony, others are of very fine sand, and one (No. 3) is of sand and gravel.

The material forming the sea bottom off our coast varies greatly, and to its character may be largely attributed the abundance or rarity of foraminifera. Sandy, gravelly, or stony ground give usually poor results, whilst places where the sea bottom is fairly fine and free from stones usually contain these microzoa in great numbers. Previous microscopical examination of Drift from various localities shows that during the glacial period similar conditions produced precisely the same results then as they do now, the clays that were finest and most free from stones being usually richest in foraminifera. To ascertain if this was also the case with the clays and sands from the Isle of Man the following table was prepared. It gives the weight of the material from each locality, what remained in the coarse and the fine sieve* (after washing), the loss in weight of what passed away through the fine sieve, and also the number of the foraminifera.

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* The sieves used for washing the material were a galvanized wire sieve, 16 meshes to the inch, and a miller's silk sieve 150 meshes to the inch.

Table showing what the Pleistocene clays and sands of the Isle of Man lost in weight through the process of washing, also the numbers of foraminifera in them:—

	LOCALITIES.	Weight of Material.	After Washing.		Material that was lost in passing through the fine sieve.		Foraminifera.
			Coarse.	Fine.	Loss.	% of Loss in Weight.	
	CLAYS.						
1	Cranston Cliffs (A)	26·0 oz.	2·4 oz.	14·0 oz.	9·6 oz.	36 %	218
7	Cliffs north of Mooragh	27·4 oz.	none	·9 oz.	26·5 oz.	96 %	1100
8	Ballure Glen (A), Red Clay in Drift	23·7 oz.	·8 oz.	4·4 oz.	18·5 oz.	78 %	1
9	Cliffs near Smeale, Boulder Clay	24·5 oz.	2·0 oz.	16·1 oz.	6·4 oz.	25 %	2
10	Cliffs S.W. of Point of Ayre	31·4 oz.	1·4 oz.	16·3 oz.	13·7 oz.	42 %	125
11	Port Lewaique Brick Works	27·3 oz.	1·8 oz.	11·9 oz.	13·6 oz.	49 %	672
12	West Craig Brick Works	21·4 oz.	·005 oz.	·4 oz.	21·0 oz.	97 %	738
13	Cliffs N. of Glen Wyllin, Kirk Michael, E.	24·0 oz.	1·0 oz.	9·4 oz.	13·6 oz.	56 %	1612
	SANDS.						
2	Cranstall Cliffs (B), Very fine Sand	24·2 oz.	·3 oz.	19·9 oz.	4·0 oz.	16 %	145
3	Shellag Braes (C), Sand and Gravel	37·9 oz.	14·7 oz.	21·8 oz.	1·4 oz.	3 %	none
4	,, ,, (D), Very fine Sand	33·8 oz.	2·3 oz.	29·2 oz.	2·3 oz.	6 %	75
5	Cliffs N. of Dog Mills, Very fine Sand	33·4 oz.	·03 oz.	32·0 oz.	1·4 oz.	3 %	64
6	Cliffs S. of Dog Mills, Very fine Sand	29·0 oz.	·2 oz.	18·5 oz.	10·3 oz.	35 %	1350

A study of this table will show that, speaking broadly, the Pleistocene clays and sands of the northern plain of the Isle of Man yielding drift foraminifera were deposited under conditions somewhat similar to those of the present day, but in colder seas. Speaking generally, with of course exceptions, the foraminifera occur more profusely in the finer textured material. The stunted growth of the forams, together with other characteristics of similar drift, both in England and Ireland, are features of these extensive deposits in the Isle of Man.

Furthermore, a reference to Nansen's most excellent account of the scientific results of the Norwegian North Polar Expedition, 1893-1896, Chapter XI.—" The Bottom Deposits of the North Polar Basin "—will show that in many cases beds of the finest textured clay contain abundance of foraminifera.

THE DWYKA OF SOUTH AFRICA.

By J. Lomas, F.G.S., A.R.C.S.

One of the impressions one gets in visiting South Africa is the great scale on which the country is built. At first, the mind is scarcely elastic enough to comprehend the magnitude of the phenomena which the country affords, and it is only after much effort and some experience that the true size of things becomes apparent.

While an observer, accustomed to European features, is staggered at the immensity, he is equally impressed with the simplicity of the problems presented to him.

The broad structure of the country is in the form of a shallow basin. The rim of the basin can be traced from near East London westwards along the southern margin of the Great Karroo. It proceeds in a northerly direction along the western boundary of the Karroo into Bushmanland, where it turns first east and then north-east, traversing the Transvaal into Natal.

It is then continued southwards, and reaches the sea about the mouth of the St. John's River.

Between this point and the Gualana River, south of East London, where we started, the rim is broken, or, rather, it has been removed by the waters of the Indian Ocean.

Filling the basin to the brim, and to overflowing, we find a great series of sediments more than 14,000 feet thick, increased in places to 18,000 feet by 4,000 feet of volcanic material, which has intruded itself, mainly into the younger beds.

The floor and walls of the basin are composed of very ancient rocks, the exact age of which it is not easy to

determine, as they are difficult to correllate with the European succession. They are certainly Palæozoic, and some, perhaps, are Archæan. The infilling rocks may range from Permo-Carboniferous to Rhætic or Jurassic. No beds of more recent date have been found within the basin.

The basin has attained its present form by folding. To the west and north the folding took place before the infilling. The folds now enclosing the south and eastern portions must be subsequent to the infilling, for we find outliers of the contained material caught up and enclosed in the more ancient rocks of the great folded belt to the south, while they fringe both the east and west sides of the Metamorphic series in Natal and Zululand.

Perhaps this brief outline will suffice to introduce the Dwyka beds, the first rocks to be laid down in the basin.

Not only do they occur as an almost continuous band round the basin, but whenever the overlying series in the interior has been pierced, the Dwyka has always been found. Thus it extends, either on the surface or below, over an immense area, embracing by far the greater part of Cape Colony, the south and eastern portions of the Transvaal, nearly the whole of the Orange River Colony, Basutoland and a large part of Natal and Zululand.

It forms a convenient geological horizon which enables the geologists of the various colonies to correllate the different beds, and this is of supreme importance when we remember that strata containing a marine fauna are absent over the whole of South Africa, with the exception of the Bokkeveld (Devonian) and the Uitenhage (Cretaceous).

The Dwyka also gives us a link with other countries in the Southern Hemisphere, for equivalents with the same special features, and presumably of the same age, are found in India, Australia and South America.

The Dwyka consists mainly of a conglomerate with a sandy or argillaceous matrix. It may be blue or green in colour at one place and brown or yellow in another.

Sometimes it is very hard and compact, and even sheared, whereas in other districts it is soft and friable, and shows no evidence of having been subject to great earth stresses.

The enclosed boulders vary very much in size and range up to 10 feet in diameter, and are composed of a great variety of rocks. Sometimes they are angular, sometimes well rounded. There is no sifting into sizes apparent, and we find them scattered irregularly through the conglomerate without any definite arrangement.

Many of the boulders, particularly the large ones, are pear-shaped, blunt at one end and pointed at the other. One face may be a plane and another rounded, and over these may be scratches or striations, often following the longer axis of the stone. These features remind us of the boulders contained in our own Boulder Clays, and the likeness is still further confirmed when the underlying rocks are examined, for they are frequently found to be grooved and striated. (Plate II.)

Other features, too, they possess in common with glacial deposits, which leave no manner of doubt that they were formed under glacial conditions.

The beds are thick in the south, and gradually become thinner as we go north. Thus, south of the Karroo they attain 1,000 feet; at Prieska, and generally in the north of Cape Colony, they are less than 500 feet.

At Kimberley only a few feet have been registered in a boring. In the north-east, 40 feet, or about, of conglomerate may be seen, but as we proceed southwards again into Natal the beds thicken.

The thickness, too, may vary considerably over a short distance. In other words, the surface on which the

deposits rest is uneven, and the Dwyka fills up old valleys. Some of these are now being re-excavated, and the pre-Dwyka landscape is gradually being unfolded.

South of the Karoo the conglomerate is overlaid by about 600 feet and underlaid by about 700 feet of shales.*

These shales are almost identical in character, consisting of exceedingly small and angular quartz grains, very uniform in size. Flakes of mica are abundant, and some included opaque granules—may be due to carbon. In a core of Lower Dwyka shale from Matjesfontein, 1,500 feet from the surface, a banded appearance is given to the mass by enclosures of lenticular pieces of fine sandstone in the argillaceous matrix.

A typical specimen of the conglomerate obtained from a boring at Matjesfontein, 600 feet from the surface, shows a dark grey matrix, very hard and compact.

It contains inclusions of a coarse-grained granite, well rounded, in which crystals of Quartz, Orthoclase Felspar and Muscovite are distinguished. Quartzite with Sericite is also common, and occurs in large angular fragments. Horizontal shear planes with a slight displacement traverse the Quartzite. The continuation of the shear planes into the matrix is very difficult to make out, owing to the fine and even texture, but as all the specimens show similar shear planes parallel to each other, it is scarcely possible that the stones possessed this feature before they were embedded in the matrix.

In a thin slice of the Dwyka examined under the microscope we see an abundance of angular and rounded grains of Quartz embedded in a fine argillaceous matrix. Orthoclase Felspar, Plagioclase Felspar, Garnet, Zircon, Quartz with Tourmaline also occur, and fragments of Serpentine, Slate, Sandstone with Sericite, and a Nepheline rock. Calcite occurs in large, irregular patches, and as infillings of cracks.

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* Rogers. The Geology of Cape Colony, p. 147.

According to the researches of the officers of the Cape Colony Geological Survey, the boulders found in the south, south-west and northern parts of the Colony come from Griqualand West, Namaqualand and other localities in the north. None have been traced to localities in the south, although the stratigraphy has been more carefully examined in that part.

The boulders in Pondoland have come from the north of Cape Colony or from the Transvaal.

Scratched boulders are found everywhere, and striated surfaces have been described from Jackal's Water in Prieska, Hopetown, Riverton north of Kimberley, in the Pretoria and Middleburg Districts, and at various localities in Natal.

The exposures at Riverton and Ngotshe, in Natal, I was able to visit and examine in detail, and of others I was only able to get a passing view.

The Riverton sections are easily accessible from Riverton Road Station. A journey of about six miles across the Veldt brings one to the Vaal River. The river at this place is about 200 yards wide, and flows through well-wooded banks about 50 feet below the sandy Veldt. Diabase crops out in hummocky bosses near the Hotel and along the banks of the stream, and Dwyka is seen overlying it in the stream bed and its margins, and can be followed up the smaller tributary channels.

An island in mid-stream shows a very extensive surface smoothed, grooved and striated, and here and there patches of Dwyka are left filling up the grooves.

The striæ run from north-east to south-west. Large boulders of Red Granite and Amygdaloid up to six feet in diameter rest on the striated floor. Some of the grooves are as much as five or six feet in depth. The Dwyka is a hard, compact conglomerate, brownish in colour, and while it is in the main of a gritty texture, it

encloses some fine-grained porcellanous bands of limited extent. So hard is the Dwyka, that pieces freshly broken from the surface retain casts of the striæ on the diabase below. A thin film of iron oxide usually intervenes between the diabase and the overlying conglomerate.

The smooth, even rock surface has been used by the Bushmen on which to carve rude outlines of deer and various mystical signs, and in the neighbourhood we found rude implements, composed of basalt, in great quantities.

Further up the river, about 1½ miles from Riverton, even finer examples of striated surfaces can be seen, and the photographs reproduced (Plate II.) I owe to the kindness of Prof. R. B. Young, of Johannesburg, who has given special attention to these interesting exposures.

Mr. E. T. Mellor has recently described numerous localities showing Dwyka and striated surfaces in the Transvaal.*

Personally, I was only able to obtain a hasty glance at one of these near Bronkspruit Station, where the railway crosses the Wilge River.

At Vereeniging a conglomerate has been found containing the well-known coal deposits of the neighbourhood.

It has been regarded as belonging to the Dwyka Series, and from the fact that coal is found in the middle of the conglomerate some geologists have made it serve as proof of an inter-glacial period. It seems a big thing to remove the ice, introduce a genial climate, and then to bring the ice over the country again to explain the presence of the coal. A similar succession is not met with in other localities, and as a *local* inter-glacial period is scarcely to be contemplated, it seems to me that the machinery is out of proportion to the product.

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* Q.J.G.S., Vol. lxi., Nov., 1905.

Mr. Mellor† expresses doubts as to the conglomerate being of Dwyka age, and suggests that it is re-assorted Dwyka belonging to a later period. This not only overcomes the difficulty, but brings the coal in its proper horizon in the Ecca beds overlying the true Dwyka.

In the east we had good opportunities of studying the Dwyka about Vryheid and near Durban.

In the Vryheid district, visited under the guidance of Dr. Molengraff and Mr. Anderson, the Dwyka is found filling an old ravine in the Barberton Beds, and many of the streams about the base of Ngotshe Mountain give good exposures. The conglomerate is a compact, greyish-brown rock, filled with pebbles, many of them striated and ranging up to five feet in length. The series here is very thick, and consists of alternations of sandstone and conglomerate. Where the conglomerate crops out there is usually a sudden drop in the stream bed, which gives rise to a series of waterfalls.

The Dwyka has evidently been subject to great stresses since its deposition, as contortions are common. Perhaps some of these took place before the Boulder Clay had become cemented and hardened into compact rock, as a forced arrangement of boulders can be made out in places.

Among the pebbles I noticed Quartzites (Barberton), Granite, Amygdaloid and Magnetic Jasper.

The underlying rocks are always the sandstones of the Barberton Series, and whenever the streams have removed the Dwyka the surface beneath is scored and striated.

Sometimes the striated surfaces are very steeply inclined. Whether this represents the original slope of the beds or is due to subsequent tilting I cannot say, but the striæ show clear signs that the ice came from the

† Geol. Survey of the Transvaal, 1904, p. 24.

north, and this agrees with the direction of boulder transport.

Dykes of basalt traverse the conglomerate, showing that igneous intrusions took place in post-Dwyka times.

We have seen already that the basin formerly extended beyond its present limits, as outliers are found south of the Zwartberg Mountains, and on the north and west isolated patches are met with in the Kalahari Desert and in Rhodesia.

It is evident, too, from the direction of boulder transport and the wonderful consistency of the glacial striæ which converge towards the basin that the ice came from the north and west. This implies high ground in those regions, and the Granites, Quartzites and other pre-Karroo rocks now found there may be the remnants of those lost mountains.

I am not concerned at present with the causes which led to the accumulation of snow and ice in these parts, extending to what is now near the Tropics. The cause was widespread, and produced similar effects in India, Australia and South America.

We may fairly regard it as an ancient ice age, and it must rank as something above the effects of local Glaciers fed by a range of lofty mountains.

We may assume that the ice first accumulated on the high parts of the rim, and gradually crept down until the basin became filled with the ice-sheet.

At first, the frontal margins of the ice would reach but a little way down the slopes, and the melting of the ice would produce streams and torrents which would carry and abrade material, the coarse being transported a short distance and the finer to a greater distance.

If, as is probable, the advancing ice came athwart the previous lines of drainage, lakes would be formed in which the finest sediment would be precipitated. I should like

to suggest that the Lower Dwyka shales found only in the south may represent this phase.

Then came the maximum extension of the ice, bringing with it coarser fragments deposited without definite bedding planes, and excavated here and there by sub-glacial streams inconstant in direction and position. The intercalated lenticles of sand may be the product of this fluvial action.

With the retreat of the ice, lakes would again be formed; the Upper Dwyka shales may be the sediments produced during this period.

The gradual shading off of the true conglomerates, through stages of increasing matrix and decreasing boulders, lend some weight to this view, and the characters of the sediments are quite consistent.

Lastly, we have the picture so often repeated in our own country of the drainage reverting to its pre-glacial channels. A glance at a geological map of South Africa will show, time after time, the Dwyka reaching as a tongue outside the rim where a stream runs over its surface. These are old drainage hollows filled with the conglomerate.

Dr. Molengraff*, Mr. E. T. Mellor, and others have commented on the interesting fact that a pre-glacial landscape is being gradually uncovered in the Vryheid, in the High Bushveld, and in those parts of the rim which were in existence before the Dwyka was laid down.

No one knows better than the members of the Liverpool Geological Society the difficulties which meet one in trying to read the meaning of our glacial deposits formed only yesterday. How much more difficult, then, must it be when the deposits are old and have undergone many changes.

* Geologische Aufnahme der Süd Afrikanischen Republik. Jahresberichtüber des Jahr, 1898.

FIG. 1.

FIG. 2.

On one or two points there was absolute unanimity among the geologists who were privileged to examine the sections of Dwyka in South Africa. One is that all doubts can now be set at rest as to their glacial origin, and another is a high appreciation of the skilful manner in which the State Geologist to the late Transvaal Government and the Directors and Staffs of the various Colonial Geological Surveys have worked out this most interesting problem.

EXPLANATION OF PLATE II.

FIG. 1.—Roches moutonnées on banks of Vaal River, near Riverton.

FIG. 2.—Glacial grooves in Diabase, partially filled with Dwyka—Vaal River, near Riverton.

ON SOME ERRATICS OF THE BOULDER CLAY IN THE NEIGHBOURHOOD OF BURSCOUGH.

By W. D. Brown.

In the low ground between the hills of Millstone Grit at Parbold with their fringe of Permian and the rising ground of Ormskirk and all the way to the coast lies a good development of Boulder Clay. In Martin Mere and about Rufford it is covered with peat and other post-glacial deposits.

At Burscough Bridge, according to a boring made by Mr. E. Timmins for the Lancashire & Yorkshire Railway Company, the glacial deposits are 240 feet thick, and consist of an upper clay 63 feet thick, then sand and gravel with shell fragments and boulder clay again below.

The glacial deposits are continued up the Douglas Valley to Wigan. The valley sides being cut into deep ravines show the rock below the drift in places.

Numerous brick pits occur over the area, and give good sections.

Some of the contained boulders are of large size, the largest found near Burscough Junction Station measuring 7 feet 6 inches by 6 feet 6 inches by 4 feet 9 inches. It is composed of Criffel Granite, and is estimated to weigh ten tons.

Another, probably five tons in weight, of volcanic ash, is to be seen at Alty's Pit at Hesketh Bank. Lake District rocks are the most plentiful, while limestone, Scotch granites and grits come next. Other boulders

commonly found are Millstone Grit, ripple-marked Keuper Marl with salt pseudomorphs, banded rhyolite, Antrim chalk and flints, chert, dolerite, purple slate with small faults, and ganister.

The limestones contain fossils such as Productus and Lithostrotion, and under the microscope are seen to be rich in foraminifera. Some are bored by Cliona and Saxicava.

Coal measure fossils, such as Lepidostrobus and Sigillaria, occur in nodules. One clay nodule included very perfect crystals of dolomite. The dolerites are sometimes vesicular, and have their cavities filled with natrolite.

In the clay itself fragmentary shells such as Turritella are found, and a piece of coniferous wood occurred in one place 30 feet below the surface. The wood was fairly fresh, and in thin sections showed evidence of much crushing.

About 70 of the boulders were sliced for determination. One of these was a diabase bearing analcime.

Wind-etched pebbles are found occasionally in the clay. One of these was described by Dr. Bather in the "Geological Magazine" of August, 1905. It is composed of sandstone, and was found two feet below the surface at the Burscough Bridge Brick Company's works. It has five facets on one side and two on the other, showing evidence of wind drift.

Others have been found as deep as 40 feet from the surface. One measuring 10 inches by 9 inches, and weighing 11½ pounds, is in shape very like the one discovered by Mr. R. D. Darbyshire 40 years ago, at Mosley, Cheshire.

Another from Littlewood, near Croston, is longer than broad; it is triangular on the upper surface and has two facets on the lower surface.

A small triangular pebble of Carboniferous chert with sponge spicules and foraminifera shows etching, and a dark rock, probably a fine-grained basalt, has been worn into a typical shape with very sharp edges.

Several quartzites and a volcanic ash were found by Mr. Lomas in Martin Mere in 1903, and exhibited before this Society.

None of the wind-etched stones show glacial striations, and the questions naturally arise, when the etching took place, and what were the conditions existing at the time.

We are not in a position to state with certainty whether the stones obtained their present characters in pre-glacial, glacial or post-glacial times.

In order to get some data to work upon, I selected three pebbles from the Boulder Clay, a granite, a limestone and a sandstone, and submitted them to an artificial sand blast where the conditions could be controlled.

Before exposing them to the sand blast they were carefully weighed, and models of each were prepared in plaster of Paris.

A vertical sand blast with a pressure of 45 pounds per square inch was allowed to play obliquely on each for ten minutes. The sandstone was further placed over the hole so as to receive the full blast vertically for five minutes.

The granite weighing 2,130 grains lost 200 grains, say 10 per cent. The limestone weighed 2,193 grains and lost 328 grains—about 15 per cent.

The sandstone weighed 1,630 grains, and with the ten minutes oblique and five minutes vertical blasting lost 835 grains.

The vertical blast, although only acting for half the time, accounted for 435 grains, while the blast at 45 degrees only removed 400 grains in ten minutes.

The surface of the limestone after the action was reduced to an even plane. The granite also resulted in a plane surface, but differential action, owing to the greater hardness of the quartz, gave it an uneven appearance.

The oblique blast produced an even plane on the sandstone, and the effect of the vertical blast was to drill a circular hole to a depth of $\frac{3}{8}$ inch.

Further experiments are in contemplation with different rocks.

SANDS AND SEDIMENTS.

Part III.—Final.

By

T. Mellard Reade, F.R.I.B.A., F.G.S.,

and

Philip Holland, F.I.C., F.C.S.

INTRODUCTION.

The Principles of Sedimentation.

To enable us to appreciate the meaning of the experiments detailed in this investigation it will be advisable to cast a glance at Nature's way of dealing with the waste of the land.

Decomposition.—The origin of the larger part of the sediments which go to build up the structure of the earth's envelope is undoubtedly that portion of the crust which lies above the sea-level. This was insisted upon by the founders of modern geological physics—Hutton and Playfair. The breaking up of the rocks is initiated by chemical forces acting along structural lines. This may result first in the division of the beds on a large scale. Carrying on the examination we find that the whole of the rocks of the globe possess divisional planes, varying from those of large mineral masses* to a structure sometimes so minute as to be seen only by the microscope, and even, as we shall seek to show, of a minuteness beyond even the powers of that instrument to reveal.

* Sedgwick "Structure of large Mineral Masses."—Trans. of Geological Society, 1835, p. 479.

The tendency to break up in definite particles of gradually decreasing magnitude is increased by the actual chemical decomposition of the rock, the solution of part of its constituents, and the carrying away of them in water.

The final residuum appears to be earthy particles, which in some cases take the form of clay in situ (see table), but which generally are carried to the sea, and so fine is the texture of this residuum that it may only, if ever, come to rest in the deepest oceans.

The mineral least subject to these chemical changes appears to be silica in the form of quartz, but even this is eventually mechanically broken up to almost infinitesimal fragments, which in some cases constitute part of beds near the shore, but in others are carried out to the ocean abysses.

Collision and Abrasion.—The fragmental origin of much of the sediment of both great and small grain is nowhere so plainly seen as in the rounded and polished grains of quartz to be found in most sediments. Though some of these grains may have been rounded by wind action, the majority—so our investigations lead us to consider—get their spherical shapes and polish from collision and attrition in water. The sands of the Amazons yield near the embouchure splendidly rounded quartzose grains. (See figs. 8 and 9, plate IV.)

In the track of the ocean liners from Liverpool to New York soundings discovered sands largely made up of well-rounded grains. (See fig. 10, plate IV.) The presence of such grains in sediments the world over, both now and throughout geological time, can hardly be explained by so local a cause as wind action.

The researches detailed in this series of papers show that there is present in most rocks quartz of infinitesimal grain, which may be separated from the larger granular matter by subsidence. (See figs. on plate III.)

In what way have these particles been produced? One cause will undoubtedly be attrition, and the rounding by collision of the larger grains. To realise how minute are the fragments broken off in producing this spherical shape we may point out that perfectly rounded and polished grains of quartz are met with of $\frac{1}{200}$ of an inch diameter, and some whose diameter is less than this. (See fig. 11, plate IV.)

When we consider that blows by collision diminish in intensity with the decreasing size of the grain, the smallness of the particles chipped off by each successive blow must be almost inconceivable. By these collisions a large part of what we have ventured to call quartz-dust will originate. Our cylinder subsidence experiments demonstrate its presence in the suspended clay.

Thus do the insolubility and hardness of quartz render its geologic life in the granular form so noticeable a fact.

Mica is another mineral found in most of the subsidence experiments. When rocks break up, this mineral is resolved to minute flakes, which, from their shape and low density, subside only slowly.

Since mica can be chemically decomposed, it will help with the kaolinisation of the felspars to produce those hydrated alumino-ferric silicates which so largely make up geologic clays.

River Sediments.—Our researches began in Part I. with an examination of recent fluviatile deposits, where it is shown that even among the deposits which roughly are classed as sands there exist many minute particles of matter which have received little attention from chemists or geologists. A reference to Table I., Part I., will show this. With what are designated "muds" these fine matters increase proportionally, reaching in the case of the Ganges at Benares 1·81 and 1·96 per cent. of the

whole,* and in mud from the Tiber above Rome at Porta Molli 1·78 and 1·80 per cent., of which 28·60 per cent. is carbonate of lime

In consequence of the rapid motion of water in rivers, the smaller particles have not time to settle, so that a sifting of the materials begins to take place; the finer matter is carried out seaward, but even with large rivers a portion of this gets deposited on the way as clay or mud, as in the Ganges and Tiber just cited, and in other rivers mentioned in Table I., Part I.

Part II. we devoted to an examination of the matter deposited in the sea or in lakes in geologic ages. It is in these deposits that the finest textured muds are to be found.

Separation by water-sifting by subsidence, has enabled us to show that certain mineral particles are selected and tend to accumulate in the supernatant water of the cylinder as the period of subsidence is prolonged.

Minuteness of Some of the Particles.

It is difficult, if not impossible, to say to what degree of minuteness these grains of matter can be, or rather are reduced. Matter in suspension differs radically from that in solution. The "particle" remains eventually the same in the smallest grain that can be caught and measured. Conceivably the "particle" may be divided and sub-divided infinitesimally. In this it differs from matter in solution, which becomes diffused throughout the liquid that dissolves it.

From these considerations it follows that minute fragmentary matter may be distributed through the oceanic waters, though not discernible by ordinary methods.

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* *i.e.* Under the special conditions of the suspension experiments as regards weight of mud put in the cylinder, time of subsidence, and height of column of water.

Contrary to some of the early generalizations, it is found by cable laying experience that the floor of the ocean is swept by currents* more or less intensely. Tidal movement affects the greatest depths of the ocean, and although in most cases the effect is small, it is probably sufficient to prevent minute particles from settling down for a considerable time.

Not only are insoluble particles existent in sea-water, but, as we have shown, particles of soluble rocks may also be present in temporary suspension.

The carbonate of lime which often exists in considerable proportions in the fine clayey matter obtained by the operations described and recorded in Table II. is not present in solution, but in suspension.

Oxide of iron has a tendency to remain long suspended. Instances are given in pages 73, 74 and 76, Part II., Proceedings of Liverpool Geological Society.

Geological Applications.

The experiments have, we think, demonstrated the existence of a mass of matter of unsuspected granular minuteness distributed throughout the sedimentary rocks of the earth.

These minute particles help to fill up the interstitial spaces of the coarser grained rocks. They constitute, as before pointed out, a large portion of geologic muds and clays that have been deposited in quiet waters near to land, and a still greater proportion of the deposits that occupy the sea-bed.

We have strong grounds for thinking that the distribution of the finest sediment, in the form of what we may call quartz-dust, is oceanic.

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* See Address of the late Admiral Sir W. J. L. Wharton, to Section E British Association, South African Meeting, 1905. Nature August, p. 451.

The reason this fact has not hitherto been fully recognised is that its presence being unsuspected it has apparently not been searched for.

The widest generalizations hitherto attempted as to the distribution of deposits on the sea and ocean beds are those by the authors of the "*Challenger*" Reports. The information gathered by that Expedition was most extensive and valuable, and the attempt at classification of high scientific importance. Like most first attempts, some of the basic ideas have, we think, been pushed a little too far, and, resting as they do on hypotheses, leave room for friendly criticism. The analyses of the deep sea oozes given in the Report are either those of the deposit as dredged or the coarser remains after washing out the finer particles. This exclusion of the fine part is, we think, unfortunate, for had it also been examined some additional interesting facts would have been disclosed.

Our analyses have been made not of deep sea oozes—for we had none—but of recent River deposits and geologic sediments.

The presence of terrigenous matter in a minute state of division throughout oceanic waters is admitted in the following extracts from the Report, p. 340:—"Further experiments have shown that sea-water with a salinity of 1·025 after remaining for over 30 days absolutely at rest, holds up in suspension finely-divided clay in amount equal to 625 tons in one cubic mile of water." Footnote (J. M.). "If these observations be confirmed by further investigations, it must be admitted that a small quantity of clay can be transported to the central regions of the great ocean basins, and, falling to the bottom, may there make up a part of the Red Clays and of the clayey matters in pelagic deposits. The amount of clay thus transported must, however, be very small, for, otherwise, it would mask the minute fragments of pumice or the organic

remains which there make up so large a part of the deposits."

In the numerous analyses of deep-sea muds and clays given in the Report no serious attempt seems to have been made to separate quartz from other mineral constituents.

The silica as we gather from the body of the Report, is presumed to be chiefly in the form of silicates derived from the decomposition *in situ* of volcanic ashes, pumice, and other sub-marine emissions. Doubtless these are largely contributory, but it is admitted that what is classed as *Red Clay* has "a great variety of chemical composition." This is so, and the fact is brought out in the Report. Our experiments on terrigenous sediments having convinced us that the sedimentary rocks of the globe are in part made up of the very finest divided matter, we have endeavoured to devise such analytical methods as shall best show the mineral composition of these microscopic and ultra-microscopic sediments and enable comparisons to be made with pelagic deposits.

EXPERIMENTAL.

Description of Specimens.

No. 1.—*Chalk from a quarry in Harpenden Lane, St. Albans, Herts., in situ.*

The quarry is now being filled up. The specimen consisted of compact lumps of which each weighed over three ounces. A white chalk.

No. 2.—*Chalk under gravel from Bowling Alley, Wheathampstead Road, near St. Albans.*

No. 3.—*Chalk from near the same spot as No. 2.*

No. 4.—*Chalk from foundation of cottages, Wheathampstead.*

These in all cases were large pieces, weighing several ounces. A full analysis was made of No. 2.

Tertiary.

Clays.

No. 5.—*A brown clay containing flint gravel, from Water End, St. Albans.*

It effervesced but slightly with acid. Contains a fine sand with both angular and spherical grains of clear quartz. There were no spherical grains of flint in the gravel got by washing away the clay. Kaolinized grains of felspar are present, also many self-cemented grains of sand in pairs and triplets. This clay was from a pipe in the chalk, which explains its mixed character.

No. 6.—*Specimen from Ayot Brickfields, near Ayot Station, St. Albans.*

A brown clay free from pebbles and flint flakes.

No. 7.—*From Leverstock Green, St. Albans—Child's Brickworks.*

A brown clay free from gravel and coarse sand.

No. 8.—*From Leverstock Green, St. Albans—Child's Brickworks.*

A very red clay free from gravel and coarse sand.

No. 9.—*From Leverstock Green, Child's Brickworks.*

A soft clay on top of chalk. It is unfit for brick making, as the bricks soften in the burning. Free from gravel.

Glacio-Marine Clay.

No. 10.—*A Boulder Clay, from Brick-pit, Cook's Lane, Great Crosby, Lancashire.*

A brown clay. The air-dried specimem weighed 3 lbs., and the whole held four oblate pebbles, of which the largest was ¾ of an inch long. It was scratched on one side. There was also shell detritus. The celebrated Gypsum Boulder of Great Crosby, weighing 18 tons, came

out of this clay, in which it was embedded some 20 feet deep. Foraminifera are abundant, also fragmentary sea shells and occasionally perfect specimens. (See Proceedings of Liverpool Geo. Soc., Session 1898-99, pp. 347-356.)

No. 11.—*Composite Chalk of St. Albans. Consisted of several bags containing lumps of chalk.*

Subaerial Clay.

No. 12.—*A very fine grey sediment underlying peat at Palé, Llanderfel, N. Wales, collected by Mr. Ruddy, on May 6th,* 1905.

On breaking up the specimen, which was very soft and yielded easily to pressure, two fragments of what resembled schistose rock were found. The whole specimen weighed 9 oz. The sand on the 30 mesh sieve had a dark green shade. There were some well-rounded grains of clear quartz and flakes of mica in the sand. The same observation applies to the much finer sand on the 90 mesh sieve.*

CYLINDER EXPERIMENTS.

Analyses of Fine Suspended Matter.

In our two former communications we drew attention to the variation in amount of suspended matter yielded by like weights of different sediments for like periods of repose, also to the persistent suspension of chalk and alkaliferous minerals. These observations have been further confirmed. We consider

* Mr. Ruddy says in a letter, "The clay I gave you is from a bed near the garden here (Palé), which is a deposit under a bed of peat where it was once a marsh. The late Mr. Robertson, C.E., sent some of it to the brickworks at Brymbo, to see if it were good for brick-making, but it was not suitable. There are one or two other beds of a nearly similar nature, on the hill. It has been used for lining reservoirs of small extent. The deposits are on a level ground, or in slight hollows. Dried, powdered, and mixed with tobacco water and soft soap it is used to paint the trees with."

the alkaliferous mineral to be chiefly mica, for mica could often be seen on the sieves and was visible on fractured surfaces of the coarse gravel. Particles also of kaolinized felspar can hardly be absent from such sediments. Their minuteness and alteration render optical recognition almost impossible. Chemical tests applied to selected white grains from the separated sands did, however, prove the presence of potash. H. Behrens' methods are useful for this purpose.*

We give here analyses of the 18 hour and 36 hour suspended matter got from the boulder clay and of the same from a composite† of the St. Albans clay.

DRIED AT 120° C.

	Boulder Clay.		St. Albans.		
	18 hour Suspended Matter.	36 hour Suspended Matter.	Composite Clay. 18 hour Suspended Matter.	Composite Clay. 36 hour Suspended Matter.	
Total SiO_2	46·47	46·17	50·16	50·01	Silica
TiO_2	0·75	0·80	0·88	0·94	Titanic Oxide
Al_2O_3	21·98	22·20	24·97	24·73	Alumina
Cr_2O_3	present*	—	—	- -	Chromic Oxide
Fe_2O_3	8·17	9·00	9·92	10·16	Ferric Oxide
MnO	0·19	0·16	0·07	0·07	Manganous Oxide
CaO	3·60	2·79	0·95	1·00	Lime
BaO	present*	—	—	—	Baryta
MgO	5·02	4·96	1·37	1·48	Magnesia
K_2O	4·11	4·26	2·62	2·57	Potash
Na_2O	0·52	0·53	0·23	0·22	Soda
CO_2	2·19	2·13	0·75	0·77	Carbonic Acid
SO_3	1·16†	none	—	- -	Sulphuric Acid
P_2O_5	—	—	traces*	—	Phosphoric Acid
Combined Water and Carbonaceous matter not determined.	5·84	7·00	8·08	8·05	
	100·00	100·00	100·00	100·00	
Sp. Gr.	2·80	2·73	2·62	2·68	

* Detectable on 4 grammes. † Due to imperfect removal of the gypsum.

* Prof. H. Behrens' Micro-chemical Analysis.—Macmillan & Co., 1894, p. 29.

† Equal weights of the dried clays well mixed.

Effect of Time of Subsidence on the Chemical Composition of the Suspended Matter.

The object of analysing the 18 and the 36 hour matter was to learn the effect of doubling the time of subsidence. The difference in the two sets of figures for the boulder clay is shown in respect of the alumina, the oxide of iron, and the alkali. The 36 hour matter has slightly more of them. The rise in alkali would appear to indicate a longer retention in suspension of the mica* in this instance. The figures for St. Albans are almost identical. Compare analysis of 18 hour matter of the Wealden Clay, p 76, Part II., Proc. of the Liverpool Geo. Soc., 1904-5, which shows a remarkable similarity in composition. The next analyses are of the clay under peat supplied by Mr. Ruddy. The small stones picked from this specimen suggested a weathered schist. Much of the interest of this peculiar deposit lies in the fact of its yielding a larger amount of cylinder suspended matter than any other of the specimens of clay or mud so far examined, viz., 21·23 per cent. On reference to the Table it will also be seen that this mud shows the highest figure for potential clay, viz., 56 per cent. The one most nearly approaching it is that of the London Clay (see Table, Part II.), which shows 49 per cent.

* A flake measuring 2 m.m. was found on a fractured surface of a pebble from this clay.

ANALYSIS OF THE GREY SEDIMENT FROM PALÉ LLANDERFEL.

DRIED AT 120° C.

	The Original Specimen.		The 18 hour Suspended Matter of the same.		
Total $Si\,O_2$	59·79	......	49·58	...	Silica
$Ti\,O_2$	0·88	......	1·94	...	Titanic Oxide
$Al_2\,O_3$......	22·12	......	29·09	...	Alumina
$Cr_2\,O_3$ ...	none	......	—	...	Chromic Oxide
$Fe_2\,O_3$ ...	1·09	......	1·19	...	Ferric Oxide
$Fe\,O$	4·10	......	3·46	...	Ferrous Oxide
$Mn\,O$......	traces	......	—	...	Manganous Oxide
$Ca\,O$	traces	......	—	...	Lime
$Ba\,O$	0·06	......	—	...	Baryta
$Mg\,O$......	1·28	......	1·31	...	Magnesia
$K_2\,O$	3·71	......	4·77	...	Potash
$Na_2\,O$ ...	1·24	......	1·60	...	Soda
$P_2\,O_5$......	none	......	—	...	Phosphoric Acid
Combined Water and Carbonaceous Matter not determined	5·73	......	7·06		
	100·00		100·00		
Sp. Gr....	2·653	......	2·746		

Here we find the suspended matter has gained 7 per cent. of alumina and 1·4 per cent. of alkali. The 10 per cent. loss of total silica is explained by the coarse sand and other granular material of a sediment quickly separating itself from the finer material by rapid subsidence when the water is at rest. The clay however, will entangle fine quartz, mica, and other potash bearing minerals with some chalk, and these will remain longer suspended; indeed, proportionately to the inverse ratio of the size of the particles.

In Mr. Ruddy's specimen, if we calculate the alkali to felspar for convenience, we get 33 per cent. for the original sediment and 42·5 for the suspended matter.

Regarding the latter as an artificial silt, our experiments afford evidence of the probable richness in alkali of river silts. Inasmuch as silt also carries nitrogenous vegetal *débris*, and often phosphates, the high fertilising power of the silts of the Nile and the Ganges can be thus explained.

It may be well to compare the two last analyses with those of the Wealden Clay *loc. cit.* for the respective differences in total silica and alumina in the suspended matters. Experimental sedimentation tells us something of the means by which the highly aluminous material of coarse rock detritus has by natural processes been washed out by water to be later on laid down and consolidated to slates and schists The presence of minutely divided matter in sediments which the experiments show in greater or less proportion to be common to all, has a direct bearing upon the production of the parallel structure of rocks known as slaty cleavage. We would refer readers for our investigations on this subject to the outline of our "Theory of Slate Structure and Slaty Cleavage,"* in which we express our belief that the secondary foliated minerals "have been developed *pari passu* with the movement of the constituent particles of the rock which have given way under shearing stresses." These developments will more readily take place the minuter the particles of the original sediment It is thus seen that mechanical sub-division will have a direct effect on the re-arrangement of matter undergoing chemical and dynamic change, so that quartz present as dust may in this form enter into *chemical* union with alumina and other bases to build up those various mineral silicates which so largely compose sedimentary rocks.

The next analysis is of considerable importance as showing the presence of residual clay in chalk to the

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* The Evolution of Earth Structure (Reade), p. 219-220.

extent of 1·39 per cent. in this specimen. (In No. 3 the residual clay is 3·75 per cent.)

No. 2 CHALK, WHEATHAMPSTEAD ROAD, ST. ALBANS.

Sp. Gr. 2·67, Dried at 120° C.

$CaCO_3$	97·37	Carbonate of Lime
$Ca_3P_2O_8$	0·48	Phosphate do.
$CaSO_4$	0·09	Sulphate do.
$MgCO_3$	0·41	Carbonate of Magnesia
NaCl	0·07	Chloride of Sodium
$Fe_2O_3 + Al_2O_3$	0·12	Oxides of Iron and Alumina
Matter insoluble in *cold dilute hydrochloric acid*, dried at 120° C.	1·39	Residual Siliceous Clay
	99·93	

Analyses of Residual Clay in the Chalk.

The siliceous clay which in No. 2 is 1·39 per cent. was obtained by treating 600 grammes, or thereabout, of a composite chalk with cold dilute acid. The separated clay was collected, washed and dried. It may be well to give shortly the scheme of analysis. Some 4 grms. of this clay was treated with diluted sulphuric acid boiling at 140°C. The clay and acid were heated in a covered platinum crucible placed in a radiator the temperature of which was kept at 130°C. The contents of the crucible were stirred at intervals, and after three hours' heating the crucible was removed from the radiator and allowed to cool. The acid extract and the residue were analysed separately by the usual methods. The silicic acid set free in the operation was dissolved from the residue by a 5 per cent. solution of pure sodium hydrate on the steam bath. An alternative plan is to heat the clay with 40 c.c. of strong hydrochloric acid in a sealed glass (Bohemian) tube at 140°C. in a Frankland's autoclave. This plan, yielding the bases as chlorides, enables the separations to be made forthwith. The glass is but slightly attacked,

for we found that 40 c.c. of acid alone dissolved in three hours at 140°C. less than 2¼ mlgms. of matter from the tube. What the acid dissolved gave reactions for lime and potash.

In the course of our work for this and earlier researches we have used both methods for decomposing clay silicates with equal success.

SILICEOUS CLAY IN THE CHALK OF ST. ALBANS' COMPOSITE.

Sp. Gr. 2·663. Dried at 120° C.

Loss on ignition and difference	...	8·15
Soluble in Acid and Alkali :—		
SiO_2	37·52	—
TiO_2	0·46	—
Al_2O_3	14·27	—
Fe_2O_3	5·04	—
MgO	1·50	—
K_2O	1·08	59·87
Insoluble in Acid and Alkali :—		
SiO_2	24·40	—
TiO_2	traces	—
Al_2O_3	4·66	—
Fe_2O_3	traces	—
K_2O	2·92	31·98

The quartz dust in any clay will obviously be in the portion insoluble in acid, but as in this particular case there are several unknown factors, we are unable to estimate its amount further than to say it does not exceed 10 per cent.*

SUBSIDENCE OF CHALK.

Cylinder experiments with finely elutriated chalk show that most of it subsides within 18 hours, for the

* Since the paper was read, Dr. G. J. Hinde kindly called our attention to Dr. W. F. Hume's—Chemical and Micro—Mineralogical Researches on the Upper Cretaceous Zones of the South of England. This Thesis is well worthy of study, and shows by numerous analyses that the insoluble residue of the chalk in various Zones is usually predominantly quartz in small fragments (p. 89).

average of three experiments gave only 0·58 per cent. for suspended chalk, and small as this was 7·39 per cent of its weight was felspathic clay. At first sight this small figure for suspended chalk seems anomalous. The explanation may lie in the quick coalescence of the particles, due to the homogeneous nature of the chalk. Dried clays will break up into suspended particles when put in water chalk will not. The large proportion of clay to chalk confirms our earlier observations that clay can hold chalk in suspension when, as appears extremely probable, both may be carried by currents to indefinite distances.*

DESCRIPTION OF THE ILLUSTRATIONS.

Plate III.

No. 1.—Rounded grains of quartz in the clay which had been separated by dilute acid from the chalk collected at St. Albans. × 90.

No. 2.—A grain of quartz with a quartz crystal attached. From clay separated from the chalk of St. Albans. × 90.

No. 3.—A quartz flake from same clay stained with oxide of iron. × 400.

No. 4.—Suspended matter (36 hours) from clay of St. Albans' composite. The slide was mounted with what persistently passed a filter of Swedish paper. Strongly refracting grains were visible on the stage of the microscope. × 400.

* Bearing on the conveyance of small particles by moving sea water, we found in one gallon taken 14 miles from Douglas, Isle of Man, 0·15 grains, or 15 grains per 100 gallons. The water had been at rest for one year before the deposit was collected and weighed. We are indebted to Mr. Treleavan Reade for the sample which was taken for us while on a cruise in the yacht Twll Du in 1905.

No. 5.—A flake of iron-stained quartz from the 36 hour *unfiltered* St. Albans clay. × 400.

No. 6.—A rounded grain of quartz from deposit of sea water collected by Mr. M. Treleaven Reade 14 miles from Douglas, Isle of Man. × 90.

No. 7.—A flake of stained quartz in clay of chalk of St. Albans. × 600.

The photomicrographs of 400 magnification in Plate A were taken on Ilford Isochromatic plates with a Zeiss $\frac{1}{12}$th oil immersion objective and C eyepiece. For Plate B Powell & Leyland's objectives with an A eyepiece were used. The illumination was by paraffin lamp and condensor.

Plate IV.

No. 8.—Rounded selected grains of clear quartz from Santarem, River Amazons. × 23.

No. 9.—Grains of quartz which passed the 120 mesh sieve. × 23. Santarem, River Amazons.

These illustrations (Nos. 8 and 9) are selected from a series of specimens (ten in all) from the River Amazons and tributaries and the Rio Negro. We are indebted for these to Mr. Henry Beasley, who was instrumental in getting them collected. Most of them contain a large proportion of rounded grains, are specially river sands, and look as if derived from granitic or gneissic rocks.

It is worthy of remark that an analysis of the water of the Amazons shows a much less proportion of matters in solution than does that of the Mississippi. (See *Evolution of Earth Structure* [Reade], pp. 268 and 260.)

× 90

1

× 90

2

× 600

7

× 400

3

× 90

6

× 400

4

× 400

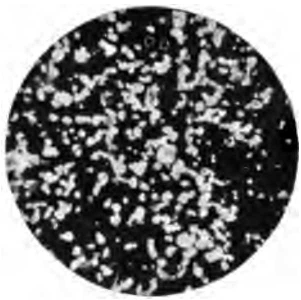
5

× 23

8

× 23

9



× 23

12

× 23

10

× 23

11

× 40

14

× 60

13

No. 10.—Rounded grains of quartz from the Atlantic Lat. 41° 9′ N., Long. 67° 28′ W., depth 24 fathoms. × 23. This specimen was one of a number of soundings taken on the route of the steamships from Liverpool to New York. The late Mr. E. K. Hayward, then secretary of the National Steam Navigation Company, obtained them for us. They all show well-rounded grains, and are, we consider, typical of sea-worn sands.

No. 11.—Micro-pebbles of clear quartz from Argile des Polder Supérieur Ziebrugge-Bruges Ship Canal. × 23. These specimens were obtained by Mr. Reade during the canal construction in company with the late Professor Rénard. They measure along the greater axis over $\frac{1}{200}$ of an inch (see Q.J.G.S., 1898, p. 576).

No. 12.—From fine mud collected whilst repairing Mediterranean cable, Lat. 38° 7′ W., Long. 30° 1′ E, depth 1,404 fathoms. × 23. The mud was washed with acid. (From Rev. F. F. Grensted, M.A.)

No. 13.—Fine quartz particles held in suspension by clay after the coarser matters had settled; × 60.

No. 14.—Quartz dust separated from St. Albans clay. The 36 hour suspended matter was treated with acid and alkali and was washed with water. Rounded grains are readily distinguished under a $\frac{1}{4}$ inch objective, but do not show well on the print. × 40.

Comparison with "Challenger" Soundings.

It may be well now to turn to the *Challenger* Report on the deep sea oozes and see if it be possible by the preceding experiments to throw any further light upon the distribution of fine particles in the oceanic basins.

The Report gives many analyses by Professor Brazier, of the University of Aberdeen, and some by the late Professor Alphonse Renard, of the University of Ghent. Brazier planned his analyses to show the composition of those portions of the mud which were soluble and insoluble in acid. His figures do not record any alkali. Renard, on the other hand, records alkali, but, unlike Brazier, does not show the matter soluble and insoluble in acid, hence the figures are not quite comparable. We ourselves consider that most, if not all, ocean deposits will contain some alkaliferous mineral, just as we found was the case in the clay of the chalk of St. Albans.

In the *Challenger* Report we have an analysis by Renard of the following deep sea deposit:—

Red Clay.—Station 29, *Lat.* 27° 49′ *N.*, *Long.* 64° 59′ *W.* *depth* 2700 *fathoms* (*Renard*), *p.* 438 :—

Silica	42·15
Alumina	20·27
Ferric Oxide	7·06
Lime	13·22
Magnesia	2·15
Potash	1·12
Soda	0·72
Carbonic Acid	9·82
Water	3·75
	100·26

This deposit but for the carbonate of lime would have been somewhat siliceous, making allowance for felspathic or micaceous mineral which the alkali may in part represent. Professor Brazier gives the following other analyses of deep sea clays:—

Red Clay.—Station 9*. Lat.* 23° 23′ *N., Long.* 35° 16′ *W., depth* 3150 *fathoms* (*Brazier*), *p.* 426 :—

Loss on ignition after drying at 230° F....		10·40
Soluble in Hydrochloric Acid, 43·74—		
	Alumina	8·30
	Ferric Oxide	9·75
	Calcium Phosphate	good trace
	Do. Sulphate ...	0·87
	Do. Carbonate ...	3·11
	Magnesium Carbonate ...	1·90
	Silica	19·81
Insoluble in Hydrochloric Acid, 45·86—		
	Alumina	9·10
	Ferric Oxide	2·04
	Lime	0·47
	Magnesia	0·95
	Silica	33·30
		100·00

If merely for a rough comparison of the insoluble in acid of this deposit with ours of the clay in the chalk of St. Albans, we calculate the oxides as tri-silicates, the quartz dust will be 9·2 per cent., as against 10 per cent. for the latter.

Red Clay.—Station 21, *Lat.* 18° 54′ *N., Long.* 61° 28′ *W., depth* 3025 *fathoms* (*Brazier*), *p.* 428 :—

In this Brazier found the insoluble in acid to be 43·66 per cent., composed:—

Alumina	5·51
Ferric Oxide	6·73
Lime	0·81
Magnesia	0·41
Silica	30·20
	43·66

Calculating the oxides to tri-silicates, as before, the combined silica to be deducted from 30·2 will be 21·7, which leaves 8·5 per cent for quartz.*

Red Clay (after the finer parts had been washed away).—Station 5, Lat. 24° 20′ N., Long. 24° 28′ W., depth 2740 fathoms, p. 425 :—

Brazier found the insoluble in acid to be 14·5 per cent., composed of:—

Alumina	1·80
Ferric Oxide	0·80
Lime	0·50
Magnesia	0·40
Silica	11.00
	14·50

The somewhat coarser quartz will come out at 3·6 per cent. only, which shows that washing the deposit has removed some of the quartz dust.

Blue Mud.—Station 213, Lat. 5° 47′ N., Long. 124° 1′ E., depth 2050 fathoms :—

The insoluble in acid is 52·84 per cent. (Brazier), consisting of:—

Alumina	7·33
Ferric Oxide	3·73
Lime	1·63
Magnesia	0·31
Silica	39·84
	52·84

Here the calculation will give 16·1 per cent of quartz dust.

* We have not lost sight of the occurrence of remains of siliceous organisms in the Red Clay, but we have no means of ascertaining the fact or the quantity.

For purposes of comparison an analysis—not given here—was made of No. 7, Leverstock Green, St. Albans, 36 hour suspended matter on the plan adopted for the clay in the chalk. No. 7 fine stuff was found to be unusually deficient in quartz dust. It will also be seen on examining Table III. that the same clay yielded only 3·25 per cent. of 18 hour suspended matter.

It is noticeable in the following analysis of the 36 hour matter of St. Albans' clay how well the oxide of iron and chalk have been retained by it when the cylinder was set at rest.

ANALYSIS OF THE 36 HOUR SUSPENDED MATTER OBTAINED FROM No. 7 ST. ALBANS' CLAY:—

DRIED AT 120° C.

Difference combined water and organic matter ...		10·34
Soluble in Acid and Alkali:—		
Silica	39·94	
Titanic Oxide	0·99	
Alumina	25·93	
Ferric Oxide	11·41	
Manganous Oxide ...	present	
Carbonate of Lime ...	1·52	
Magnesia	1·23	
Alkalies	1·72	
		82·74
Insoluble in Acid and Alkali:—		
Silica	6·08	
Titanic Oxide	0·34	
Alumina	0·42	
Magnesia	0·08	
Alkali	traces	
		6·92

This cylinder prepared fine sediment is obviously a ferruginous clay containing little quartz dust.

The amount of quartz dust in the deposits we have discussed may be more or less than we show, for we are well aware of the qualifications that belong to provisional calculations of this kind. The aim has been to compare naturally formed fine deposits with those artificially prepared by the means described in this and in former communications.

The All-Pervading Presence of Quartz Dust.

The presence of quartz dust in all the sediments examined by us naturally led us to seek it elsewhere. The preceding is an attempt to apply our experimental results to an interpretation of Professor Brazier's analyses. Unfortunately, we could only estimate the amount of quartz indirectly, so must present our figures for what they are worth.

Professor Brazier's analyses of sea deposits show some to be not very unlike those obtained by the cylinder method. It would appear there was no special quest of quartz dust, perhaps from lack of material or because its presence or absence did not concern the enquiry. Any quartz dust in the sea deposits will have been included in the SiO_2 of that portion which acid treatment did not dissolve.

It is clear from our own analyses of the Tertiary clays that quartz dust is present in shallow water sediments. Not only is this so, but the analysis of the residual clay of the chalk of St. Albans—which itself is usually considered to be a moderately deep water deposit—discloses the interesting fact that here also quartz dust is found associated as usual with clay, iron oxide, and some alkaliferous mineral, just as was the case in the sea deposits analysed by Renard and Klement.

RECAPITULATION.

On reviewing the whole of the experimental work we venture to think that the following geological inferences may justly be drawn:—

1.—That there exists in the crust of the earth a large and unsuspected volume of sedimentary matter of exceeding minuteness, grading from grains just visible to the naked eye to particles not resolvable by the most powerful microscope.

2.—That these particles are in some measure due to the decomposition of the various classes of rock composing the earth's lithosphere, and partly to mechanical collision and attrition in the wear and tear of eons of geological time.

3.—The existence of these sediments of finest texture cannot be explained, except by the fact of the survival of their constituent particles through long periods of geological time—the time they have been in the geological mill. The hardest mineral is quartz. This and zircons according to Mr. A. Dick, are least liable to decomposition, for the latter also occur in sands and throughout the sedimentary rocks, and must have been used many times over.*

The finest of this sediment we have called quartz-dust. This dust appears to originate from two causes: one by collision and abrasion, as already explained, the other by breaking up along cleavage planes. Collision and abrasion produce the rounded, sometimes spherical, grains so common in quartzose sand, and the chips broken off in this way go to make up the "quartz dust."

4.—The other portion of the finely divided matter consists mostly of clay and iron oxides, which are present even in the clearest sea-water, and some mica. Carbonate

* See p. 526, "Memoirs of the Geological Survey of England and Wales," Vol. i, Descriptive Geology, by W. Whitaker, B.A., F.R.S.

of lime is often found, and, as our suspension experiments have conclusively shown, it is held up by the clay and is present in the form of particles and not in solution.

5.—This finest—we may call it micro-sedimentation—some of it the product of agencies at work for millions of years, plays an important part in the building up of the earth's crust. By metamorphic agencies, to which from its finely divided state it is specially susceptible, it helps to form slates and schistose rocks; indeed, quartz grains are a principal constituent of many of them, particularly of slates of coarse texture.

6.—The distribution of this finely divided matter is world-wide. The particles are so small that the lightest may be carried about by the least movement of the water. Thus, it is not improbable that the bottom depths of the ocean hold more matter in suspension than is found in layers of water nearer the surface. The fact that ocean soundings often show soft sedimentary matters graduating in a few inches to stiff clay points to this conclusion.

7.—We have shown that some of the finest of the sedimentary matter may remain buried among the coarser products of river denudation, while other portions as fine are carried out and deposited in the ocean depths. Between these we may expect every grade of sediment to occur.

8.—Finally, we have shown that the sea may hold, carry about and distribute such fine or microscopical sediments in quantities, if not commensurate with, second only in importance to the matter held in solution.

ANALYSES.

No. 11. posite Chalk of Albans.	No. 12. A Grey Sediment from Palé Llanderfel, Wales.	
—	2·65	The average Sp. Gr. of the five St. Albans' Clays was 2·71, and that of the Isle of Wight specimens 2·68.
None	0·45	
None	0·46	
None	0·68	
100·00	98·41	
99·51	13·60	
—	22·12	
—	0·88	
—	5·19	
—	56·07	
0·58 §	21·23	

f felspathic clay and quartz

PROCEEDINGS

OF THE

Liverpool Geological Society,

SESSION THE FORTY-EIGHTH,

1906-1907.

Edited by R. W. BOOTHMAN ROBERTS, F.G.S.

(The Authors having revised their own Papers, are alone responsible for the facts and opinions expressed in them.)

PART 3. VOL. X.

LIVERPOOL:
C. TINLING AND CO., LTD., PRINTERS, VICTORIA STREET.

1907

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ADDITIONS TO THE LIBRARY OF THE LIVERPOOL GEOLOGICAL SOCIETY, 1906-7.

The usual Proceedings and Transactions of the various Scientific Societies have been received for the Library of the Society during the past Session, also:—

British Association Report, 1906.—York Meeting.

British Museum.—"Catalogue of Tertiary Fossil Vertebrata of the Fayûm, Egypt," 1906.

Geological Survey of the United Kingdom.—"Summary of Progress for 1905."

Geological Survey of Canada.—Annual Report, 1905. "The Cruise of the Neptune." Maps, &c.

Palæontographical Society.—Vol. lx., 1906.

Smithsonian Institution.—Annual Reports, 1905 and 1906.

United States Geological Survey:—

Annual Report, 1905-6.

Monograph, l.

Mineral Resources, 1905.

Atlas Folios. Topographical Atlas Sheets.

Bulletins. Professional Papers, &c.

PROCEEDINGS

OF THE

LIVERPOOL GEOLOGICAL SOCIETY.

SESSION FORTY-EIGHTH.

OCTOBER 16TH, 1906.

THE VICE-PRESIDENT, J. BRUCE, M.A., in the Chair.

The Officers and Members of Council for the Session were duly elected.

THE HON. TREASURER gave his Annual Statement of Accounts, which was unanimously adopted.

MR. T. B. SUTTON, Stonehouse, Bebington, Cheshire: proposed by H. C. BEASLEY and J. LOMAS, F.G.S.; and the REV. W. LOWER CARTER, M.A., F.G.S.: proposed by J. LOMAS, F.G.S., and Dr. DWERRYHOUSE, were elected Ordinary Members.

EXHIBIT :—

Silt containing shells, from the bed of the St. Lawrence River, by W. D. BROWN.

Owing to the indisposition of MR. BEASLEY, the Presidential Address was postponed, and the following Paper was substituted :—

"ON THE ORIGIN OF THE TRIAS."
By J. LOMAS, F.G.S.

NOVEMBER 13TH, 1906.

THE PRESIDENT, DR. A. R. DWERRYHOUSE, in the Chair.

EXHIBITS :—

A Sandstone Slab with markings and some wind-etched pebbles, from the Trias of Lincolnshire, by DR. DWERRYHOUSE.

Specimens of Slate showing Graptolites, by W. SCHOFIELD.

MR. H. C. BEASLEY then read his Presidential Address, postponed from last meeting :—

"SOME RESULTS FROM THE RECENT FINDS AT STORETON."
(With Lantern Illustrations.)

DECEMBER 11TH, 1906.

THE PRESIDENT, DR. A. R. DWERRYHOUSE, in the Chair.

The Meeting was held in the Zoology Theatre at the University, and was open to the public.

A Lecture, entitled "Triassic Reptiles, with special reference to Footprints," was given by A. SMITH WOODWARD, LL.D., F.R.S., F.G.S. (The Lecture was illustrated with Lantern Slides.)

JANUARY 8TH, 1907.

THE PRESIDENT, DR. A. R. DWERRYHOUSE, in the Chair. With the VICE-PRESIDENT in the Chair, vacated for the time by the President, the following Paper was read :—

"THE GEOLOGY OF INGLEBOROUGH AND DISTRICT."
(With Lantern Illustrations.)
By A. R. DWERRYHOUSE, D.Sc., F.G.S.

FEBRUARY 12TH, 1907.

THE VICE-PRESIDENT, J. LOMAS, F.G.S., in the Chair.

EXHIBITS :—

A Wind-Etched Pebble from the Boulder Clay near Burscough, and a Specimen of Granite, by W. D. BROWN.

Rock specimens from East Africa, by W. MCGREGOR ROSS.

The following Papers were read :—

"SOME COMPARISONS IN THE WEATHERING OF BASALT."
By T. H. COPE, F.G.S.

"NOTE ON A CHEIROTHERIUM PRINT RECENTLY OBTAINED FROM STORETON." By H. C. BEASLEY.

"DESCRIPTION OF THE LARGE FOOTPRINT SLAB AT THE UNIVERSITY." By J. LOMAS, F.G.S.

MARCH 12TH, 1907.

THE VICE-PRESIDENT, J. LOMAS, F.G.S., in the Chair.

The following Paper was read :—

"THE SUPERFICIAL GEOLOGY OF THE DISTRICT BETWEEN PRESTON AND LANCASTER."
By E. DICKSON, F.G.S.

APRIL 9TH, 1907.

THE PRESIDENT, DR. A. R. DWERRYHOUSE, in the Chair.

EXHIBITS :—

Coal found in Boulder Clay near Beaumaris, by T. H. ALLEN.

Coal Fossils from near Littleborough, by W. SCHOFIELD.

The following Paper was read:—

"ANALYSES OF LUDLOW ROCKS."

By T. MELLARD READE, C.E., F.G.S., and PHILIP HOLLAND, F.I.C.

FIELD MEETINGS:—

1906.

Mar. 24th—Storeton.

Leader—H. C. BEASLEY.

May 12th—Storeton (Joint Excursion with the North Staffs. Field Club and Liverpool Biological Society).

Leader—H. C. BEASLEY.

June 9th—Hilbre Island (Joint Excursion with the Liverpool and Manchester Biological Societies).

Leader—Professor W. A. HERDMAN.

1907.

Mar. 29th to Apr. 2nd—Colne and District.

(EASTER EXCURSION IN CONJUNCTION WITH THE YORKSHIRE GEOLOGICAL SOCIETY.)

Leader—ALBERT WILMORE, B.Sc., F.G.S.

THE LIVERPOOL GEOLOGICAL SOCIETY, in Account with W. H. ROCK, Hon. Treasurer.

Dr. SESSION 1905-1906. **Cr.**

Dr.	£	s.	d.
To Rent, October, 1905, to October, 1906..	5	0	0
,, Tinling & Co.—Printing for Session ...	8	17	5
,, Tinling & Co.—Printing Proceedings, 1904-1905	16	14	10
,, Tinling & Co.—Printing Proceedings, 1905-1906	18	0	0
,, Mrs. Ellick—Teas and attendance, &c.	7	3	11
,, Secretary's, Librarian's and Treasurer's Expenses	3	4	10
,, Geological Magazine for Session	0	18	0
,, Palæontographical Society, 1906	1	1	0
	£61	0	0
,, Balance carried down	10	11	9
	£71	11	9

Cr.	£	s.	d.	£	s.	d.
By Balance from Session 1904-5				19	4	9
,, Subscriptions, &c., received :—						
1904-5—Arrears	£4	14	6			
1905-6—Subscriptions ...	41	4	0			
Printing Fund	0	15	6			
Sales	2	10	0			
1906-7—In Advance......	3	3	0			
				52	7	0
				£71	11	9
By Balance brought down				£10	11	9

Audited and found correct,

(Signed), HENRY CAPPER, GEO. H. ASHWORTH, } AUDITORS.

(Signed), W. H. ROCK, HON. TREASURER.

LIVERPOOL, *16th October, 1906.*

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* Have read Papers before the Society. † Contribute to Printing Fund.

LIVERPOOL GEOLOGICAL SOCIETY.

PRESIDENT'S ADDRESS.

Read 13*th November*, 1906.

In welcoming the members to the Forty-eighth Session of our Society I have to congratulate them on its continued vigour and activity.

Although the actual membership does not increase to the extent that some of us wish, the number of workers forms a very fair proportion of the total number of members, and the proceedings for the last session give evidence of sound work and record matter of great geological value.

I think we have cause for congratulation in the fact that within the last few months we have been brought into personal contact with some other societies in neighbouring counties by our joint field-meeting with the North Staffordshire Field Club during our Easter excursion and the visit of the same club to Liverpool in May, and later by the visit of the Yorkshire Geological and Polytechnical Society.

The visits were in part owing to the fine display of fossil footprints during the summer at Storeton, but we must hope that they will be only the beginning of a more extended intercourse with the kindred societies of adjoining counties, which cannot fail to be of advantage to our local work in counteracting that tendency to narrow views which it requires such constant care to avoid when working in a restricted area.

We have to lament the loss of one of our oldest members, Mr. Michael Fitzpatrick, who was elected a member in December, 1872. We seldom of late years saw him at our meetings—he was present once during our last session—but he has constantly taken an active and practical interest in the encouragement of the study of science in Liverpool, and will be greatly missed by his friends and all associated with him.

Undoubtedly the most important event as regards local geology has been the display of fossil footprints at Storeton, for which we are indebted to the generous appreciation of the interests of local geology by Mr. Chas. Wells, the present proprietor of the quarries. The footprints have been found there for the last two generations, but they have never been before displayed so advantageously for the student. The few years after their first discovery in 1838 they naturally attracted the interest of all geologists, and the efforts of the members of the Literary and Philosophical Society and the Liverpool Society of Natural History, aided by the then proprietors of the quarry, have preserved for us the large slabs still to be found in many museums. The size of the slabs, when we consider the means then available, gives some idea of the earnestness and energy of those concerned. The largest I know of is one presented to the British Museum by Mr. Tompkinson, who I believe at that time was connected with the working of the quarry; it measures about 7 feet in length. The next in size are the series of slabs in the Bootle Museum.

As might be expected, great improvements in the methods of quarrying have been made during the sixty and more years that have since elapsed, and these have enabled Mr. Wells to raise the slabs of larger dimensions, showing more unbroken series of prints than was formerly possible; he has allowed them to stand

undisturbed for the inspection of students whilst the coating of clay weathered off naturally and exposed the finer details, whose existence was unsuspected.

There are about 20 slabs, varying in size from 3 or 4 feet superficial to 60 feet on the largest, and each slab is well worth preserving. Besides these there are several smaller ones, all of considerable interest.

Such an opportunity was not to be neglected, and the study of several hundred square feet of fossil footprints has unfortunately absorbed the whole of the limited time at my disposal, and has prevented my pushing on those investigations regarding the Upper Trias that I hoped would have enabled me to give a continuation of the subject of my last year's address.

The work of recording and describing the various forms of footprints as they come to light during the weathering of the slabs is still in progress and incomplete, but many facts have presented themselves and suggest the reconsideration of older theories and the genesis of new ones.

It is this, as it were, "by-product" of the work I have been doing that I propose to deal with to-night.

The facts may be arranged under two heads, viz.:—

I. Those relating to Physical Geology, and

II. Those relating to Palæontology.

The two are so intimately connected that it is difficult to keep them entirely distinct, and investigations into the physical geology and the palæontology of stratified rocks cannot be carried on independently of one another. The mass of detailed record of fact and theory connected with each must prevent anyone from being an expert in both until some means can be devised of compressing the record into a more manageable form.

The footprints are found now in three beds, separated a few feet from each other, at the north end of the south

quarry. The earliest were found, I believe, at what is now the south-western portion of the large quarry at present worked, but the whole of the southern portion is now worked out and enclosed and partially used as gardens. At the south-eastern corner, where the old tramway for Bebington leaves the quarries, the footprint beds are a few feet above the rail level; about half-way between that point and the embankment on which the by-road runs across the quarry the footprint bed is rather higher, and from it many years ago I obtained a good-sized slab, which from the character of the prints would seem to be the same as the lowest bed of the three now exposed. With the continuation of the beds along the east face from near the by-road just mentioned to the present workings you are all familiar. We may fairly conclude that the beds were continuous over the whole length. The footprint bed is also exposed on the west face of the north quarry now closed, where it seems to dip rapidly to the west, and I have heard that many were found there formerly. The bed is not at the same level we should expect from its dip to the south quarry, but many faults both N. and S. and E. and W. intervene, and its actual horizon is uncertain. There is no proof of the footprint beds in the various quarries in Wirral and Liverpool being parts of one continuous bed, nor is there any proof that they were synchronous. From the evident shallowness of the water one could hardly expect them to be the former, or, except within a very wide limit, the latter. It is probable that in each district there was a period during the accumulation of these sands when the climatic or other conditions were such as to favour the formation of these shallow "slacks," but these conditions were not necessarily present at the same time in each. The footprint bed at Runcorn where it has been actually proved would seem to occupy a similar position to that at

Storeton, but we must remember in how very few instances the footprints have been actually recorded as found in situ there, though they are found in the spoil heaps over the whole area which has been quarried. Of the position of the beds in which footprints have been found at Helsby and Daresbury I have no record. Those at Warrington and at Lymm would point to a higher horizon, and I think that if the generally received opinion now that the sands were accumulated by wind action be correct we might expect the shallow lagoons to be of very limited extent and of more or less temporary existence.

A fresh survey of the faults in the neighbourhood of Storeton in the light of further exposures, opened since Mr. Morton constructed his map, is much to be desired, together with a careful survey of the Runcorn and Weston sections and accurate mapping of the faults. The latter would show the probability or otherwise of the footprint beds in the two areas being on the same horizon. There is no need now to insist on the fact that exactly similar beds are by no means necessarily contemporaneous; it is unlikely that they would be. It is necessary to guard against the supposition that because footprints found in one bed are dissimilar from those in an underlying one, the lapse of time between the deposition of the beds is considerable. For instance, the majority of the Cheirotherium prints in the upper bed at Storeton are large, and the digits widely extended (" sprawling " is not a scientific description, but it conveys a very good notion of their appearance), while the smaller prints are not very numerous and the surface is much cut up by sun-cracks. Those of the next bed below are of a neater and smaller type, are associated with innumerable small prints of several different kinds, and are on a very smooth, continuous surface.

The area of which we have any at all accurate

knowledge is very limited; also the consistence of the material in which the prints were made and its thickness affect the form of the prints and the gait of the animals quite sufficiently to account for slight differences that might otherwise be thought due to a difference of species.

A temporary sheet of water may occupy the same area for many successive seasons, but the shifting of the sand may alter the position of another every year.

A good deal may be learnt from the area of sandhills on the Cheshire and Lancashire coasts, where, however, the conditions are peculiar. The sea wastes the coast-line as fast as, or faster than, the sand dunes advance to leeward, and on the windward side no fresh dunes are formed. But on an open area far removed from the sea, as we now suppose our district to have been in Triassic times, the conditions were different.

It may be permissible for an instant to picture what might have been the case in Triassic times.

Probably we were removed many hundreds of miles from the ocean, the continental land extending far to the westward. Imagine also a range or ranges of mountains to the west and south between us and the sea. What would then be our condition as regards climate? Shut off by the mountains from the moisture-bearing winds and the moderating influence of the sea upon the temperature —we should have an arid climate, clear sky, and consequently a considerable diurnal variation of temperature that would disintegrate the rocks as rapidly as rain or ice, and the wind would distribute the resulting débris. This description may be correct—there is no geological evidence that I know of to disprove it—and if true, goes a long way to explain some of the peculiarities of our Triassic sandstones. The main features of the picture are all we can hope to recover with any certainty; some of the details may perhaps be vaguely discerned

through the haze of time that seems able to resist all our attempts to penetrate it; still here and there we find vulnerable spots and glean a modicum of knowledge of the secrets it enshrouds.

One of these spots presents itself in the organic remains of which a few at least are preserved in some form in almost every stratified deposit, and although our sandstones are not stratified by water and contain no remains of a marine fauna, still the footprints which they have retained record the presence of numerous land animals and enable us to put a little life into the picture.

The recent finds add some knowledge in this direction, and present us with one or two new forms and with some fresh details regarding others previously described. Unfortunately, in no single instance has any bone been found to lead us to a knowledge of other parts of the animal.

The beds above the footprint beds are of a softer stone, have few partings and no impervious ones; the water, therefore, is found to collect on the top of the impervious stratum in which the footprints are found. Below the footprint beds there are several thicker layers of marl and clay at intervals, but I do not think there is any authentic record of footprints having been found in these. It would be interesting to know if this is actually the case.

This shows a slight change in condition in this particular area, but I think the change was probably of but slight importance as regards the whole of the Cheshire Keuper. Probably continual changes were going on over the whole district, the area affected in each case being extremely limited.

The thicker marl bands are often found to really consist of alternating thin beds of coarse and fine material, with every appearance of their having been deposited in

water, though the material was probably first carried by the wind and dropped into the water.

Ripple-marked surfaces are particularly well shown on the slabs raised this year. The ripples are occasionally traceable across the large prints. This is probably the result of a foot being impressed on some previously formed ripples, not to rippling after the impression. Had the print been formed previous to the rippling, then some of the material whose movement caused the ripples would undoubtedly have partially filled up the hollows of the print, instead of which they are filled with sand.

There are other indications of moving water, little runnels of water branching like the fine stems of a recent plant, or wider channels, with the materials carried down and arranged in regular stream courses, reminding one of a road-side gutter on a showery day. The deposit is often micaceous, and interferes with the clearness of the prints where it touches them.

On the second bed from which the finest slabs have been raised, there is a complete absence of desiccation cracks, which so often interfere with the footprints elsewhere. The cause of this is worth investigation. In the bed above they are of frequent occurrence.

However interesting may be the investigation of the physical conditions under which the rocks quarried at Storeton were deposited, the study of the traces of animal life the rocks have yielded must be of at least equal importance.

Not only has the large extent of surface we have available for study given us far more individual prints, but the larger size of the slabs has made it possible to note the relation of these prints to one another with greater accuracy than had been practicable before, and has enabled us to speak with more certainty on one or two points regarding which there was some suspicion that we were accepting as facts what were only theories.

We will deal first with the Cheirotherium footprints which form the most striking feature on almost all the slabs. We find that although we have the tracks of a number of individuals, they preserve in every case the linear arrangement which had been noticed in the few series already known, and that they have the same rhythm of footfall and the same length of stride in proportion to the size of the foot and presumably of the animal.

Finding on slab after slab the same rhythmic footfall, the same even stride, the same straight course pursued without a sign of hurry or hesitation or of turning aside, one is tempted to enquire whether these are indications of the mental characteristics of this animal of which we have so little certain knowledge even as to its physical peculiarities. It would appear to have had a definite purpose in view, and possibly some day we may come upon indications of the achievement of that purpose and the result, whether tragedy or comedy. At present imagination has the field entirely to itself.

A passage quoted by Professor Lapworth in an address to the Liverpool Biological Society, to which many of us had the pleasure of listening some years ago, is brought to my mind. "The stony science possesses its realms of dim and shadowy fields in which troops of fancies already walk like disembodied ghosts on the old fields of Elysium, and which bid fair to be quite dark and uncertain enough for all purposes of poetry for ages to come."

At the same time it is our present business to do what we can to lessen the darkness and uncertainty referred to.

The idea that the Cheirotherium was a Labyrinthodont still survives. There is no doubt that Owen's suggestion with regard to its probability was perfectly justifiable on the evidence then available, but Professor Miall's papers, notably his report to the British Association, 1873, should

have shown what grave doubts must exist regarding this identification, and more recent work only tended to strengthen Professor Miall's contention.*

The Labyrinthodon was, as far as we have any evidence, a long low-bodied, short-limbed, tailed amphibian.

(1) A short-limbed animal with a low habit of body would probably leave some trace of the drag of the under surface of its body against the ground. Of this or of any trace of a tail we have no indications connected with the prints recently exposed.

(2) An animal of this form would not arrange its footprints in a straight line.

Where I have been able to see them the footprints of such animals are wide apart. The prints that in arrangement approximate most closely to our fossil prints are those of the longer-limbed animals, the horse and ass, as anyone can see if he will examine carefully the series that are ready made to his hand any fine Saturday afternoon on the stretch of sand from New Brighton to Leasowe.

As long as the Labyrinthodon was regarded as a gigantic batrachian the difference in size between the hind and fore foot (and presumably between the hind and fore limb) lent some support to the Labyrinthodon theory. Where the hind limbs greatly exceed the fore limbs in strength and length, *e.g.*, in the frog and kangaroo, progression is by a series of leaps. This could hardly have been the case with Cheirotherium without some traces of it having been shown in the numerous tracks before us, but we find none. The even order of the prints shows no sign of violent action, and the feet are evenly planted

* Brit. Assn. Reports, 1873. "Report on the structure of the Labyrinthodonts," by Prof. Miall, p. 246. "Amphibia and Reptiles," by Hans Gadow, p. 83. See also a Paper by the writer on "The Fauna indicated in the Lower Keuper Sandstone of the neighbourhood of Liverpool."—Trans. Liv. Biological Soc., Vol. xvi., 1902.

instead of the anterior extremity of the hind foot having been more deeply impressed, as would have been the case with a leap.

As I have pointed out elsewhere, the Cheirotherium was a digitigrade animal. No part of the metatarsal or metacarpal portion of the feet usually coming in contact with the ground, except the pads in the centre of the print which probably cover the distal extremities of the metacarpals and metatarsals.

During the mesozoic period there existed another group of animals with the hind limbs greater than the fore, namely, the Dinosaurs. Of these the Iguanodon is a typical example, and he has fortunately left us some of his footprints in the Wealden of the south of England. He, however, walked on his hind legs only. It would be very interesting if a series of his tracks could be seen, but as the prints are very large, there is but little chance of a long series being available for study.

The possibility, if not the probability, exists, that a connection may be found between the Cheirotherium and the Dinosaurs.

Among the various forms of Cheirotheroid footprints met with in the recent find, a rather remarkable one is the print of a very small manus with only four toes usually shown, and instead of its being half or one-third the size of the pes, it is only about one-seventh. A fine series of these has been given to the Liverpool University by Mr. Wells, and is to be seen in the vestibule of the Zoology department.

It has been before noted that in the normal Cheirotherium prints the small fore foot made no deeper impression than the large hind one.

In the present form where the disproportion is still greater the small fore foot sank no deeper than the hind, thus emphasising the fact that the greater part of

the weight of the body was borne by the hind limbs and only a very small part by the fore; in fact, it would seem that the latter were used mainly for the purpose of steadying the body whilst in motion rather than in supporting it.

It has been suggested to me that the animal may have been something akin to the Stegosaurus—but though the restoration of this animal is well known and a rather popular illustration of geological lectures, it is extremely uncertain how far the restoration is correct. It is even doubtful whether the dermal armour that adorns its back and is its most striking feature really occupied that position, and what more immediately concerns us is that but little is known of the bones of the extremities. The hind foot probably had but three functional digits, and there is imperfect evidence of five in the fore foot.*

We have not found much to guide us with regard to the nature of the integument of the Cheirotherium, except as regards that of the sole of the foot. Hitherto, with the exception of one specimen figured and described by Professor W. C. Williamson,† the evidence has not been absolutely satisfactory. Owing to the beautifully smooth surface of most of the slabs now under review, nearly every footprint shows very perfectly a surface covered with flattened circular tubercles about 2mm. or more in diameter, and these are observed on both pes and manus of every variety of Cheirotheroid print.

Certain curious markings are found on many of the slabs that *may* have been caused by contact with some part of the body covered with bristles. The markings are difficult to account for, and though the explanation given is possible, it may at present be regarded only as a more or less wild suggestion.

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* Outlines of Vertebrate Palæontology. A. S. Woodward, p. 211.

† Quart. Jour. Geol. Soc., Vol. xxiii., p. 56.

Owing to the perfect condition of the prints, the nails with which the digits are armed are very clearly shown on the fore foot as well as on the hind. There was a little uncertainty on this head hitherto.

Before leaving the Cheirotherium prints I should like to point out that the Cheirotherium Storetonense is supposed to be the particular beast whose tracks are found at Storeton, but no other specific distinction is recorded. Unfortunately, in the collectors' eagerness to name their species, each locality has been honoured with a particular species supposed to be found there, without any great care being bestowed on a description of its particular characteristics.

This was all very well when the specimens were few, but it is very troublesome to later workers. The number of species has been needlessly increased, whilst the specific distinctions have been neglected.

Now we have a great number of varied forms of prints exposed near enough to each other for easy comparison, and it is impossible to suppose that they are all the prints of one species. I have been very unwilling to admit this, but the study of those now on view has convinced me against my will. I do not now think that the difference in the age of the individuals or in the consistence of the mud in which they were made can account for the varied forms. If it were so, it ought to be easy to find a complete series from the most slender to the most stout and "gouty." I do not say at all that this is impossible, but at present I have not succeeded in doing it.

The tracks of numerous smaller animals present material for prolonged study and of greater interest perhaps than the large and more striking ones. They are of great variety, and promise to give us examples of some hitherto undescribed forms. There is a short broad print

shown in series on several slabs, which fairly corresponds with a single print that was found at Storeton about twelve years ago, and which Professor Seeley described. He considered it probably the print of an anomodont reptile. I hope we may hear more of this later on, as the two slabs that are going to South Kensington have each a number of these prints upon them. Another rather novel form is a small five-toed print with the two outer toes pointing somewhat backwards, like the prints found at Hollington, Staffordshire, but much smaller.

The ordinary Rhynchosaurus footprint is particularly plentiful. The little beasts must have swarmed over the mud banks, and there seem to be two or more varieties of these.

Another interesting print is one of which there are only a few examples, and these not very perfect, but which may possibly turn out to be Hyperodapedon,—a lizard allied to the Rhynchosaurus, but much larger,— of which many of the bones have been found in the Trias of other parts of the country, but the footprint has not been identified at present.

The most noteworthy fact in connection with the finds at Storeton is that on some 400 square feet of surface we have footprints of at least ten quite distinguishable varieties, probably made by as many different species of four-footed animals, most of them certainly, all of them probably, reptiles. The number of individuals was very large, but as it is impossible to say how many prints were or were not formed by the same individual, it would be useless to attempt to make an estimate. These footprints were all made within the limited period, during which the mud was in a sufficiently soft state to take the impression of the feet.

Probably the animals were attracted to this spot by the near presence of water, but, making every allowance

for that, we cannot fail to be impressed by the fact that there was an abundant fauna in the district.

These must have required eventually a supply of vegetable food, however much they may have preyed upon each other, and a flora of some kind must have been within reach, but of this the recent finds at Storeton give us no indication. Probably the conditions were such as to destroy all trace of its existence.

After all, the results of the find must seem very meagre to those who have not had practical experience of the slow accumulation of geological facts regarding any one period of the earth's history, but such as are inclined to complain may find consolation in that there is still plenty of room for geological speculation and still more for geological research.

It is only by persistent attack that any of the carefully guarded secrets of Nature can be won, and for that I am devoutly thankful when I look back on the pleasure I have experienced in the small share I have taken in such work, and forward to that which I still hope to experience in the future.

DESERT CONDITIONS AND THE ORIGIN OF THE BRITISH TRIAS.

By J. LOMAS, A.R.C.S., F.G.S.

Problems connected with the Triassic rocks must always be of special interest to the members of this Society, and none can be more fascinating than those which deal with the conditions under which they had their origin. The matter has been very ably discussed in two Presidential addresses given to this Society, first by Mr. W. Hewitt in 1892, and later by Mr. H. C. Beasley in 1905. In both addresses comparisons were drawn between the features which characterise our local rocks and those exhibited by the deposits now being accumulated in the deserts of Central Asia.

It is generally conceded now that the Triassic rocks of our Islands are not of marine origin but true continental deposits, and the view has of late gathered strength that the climate was arid when they were laid down. We can only hope to reach a safe conclusion by a critical examination of existing deserts.

We are inclined in the first place to ask "What is a desert?" It is usually regarded as a region characterised by great heat and low rainfall, and yet Sven Hedin crossed the Takla Makan desert in a snow storm with the thermometer registering $-24°C.$ to $-31°C.$, and in other typical deserts the rainfall may be as high as in some parts of our own country.

Perhaps the root meaning of the word expresses best and in the most comprehensive way what a desert really is—a place unbound from associations with man. Some deserts owe their desolation to shifting sands, bare rock or "sour" soils. Others result from a covering of freshly extruded lavas or volcanic ashes. Some have

soils which are permanently frozen or covered with perennial snow, and again others may be places from which glaciers have recently retreated, leaving a soil on which vegetation has not obtained a foothold. At the close of the glacial period many thousands of square miles of our own country were left sterile and incapable of sustaining life, and we have large areas of blown sand in our county with wind-etched pebbles and other characteristic desert features.

We need not follow the different varieties of deserts further but confine ourselves to a consideration of the activities now at work in some typical sandy deserts, such as we suppose to have existed in Triassic times.

SANDY DESERTS.

Rainfall.

As a rule sandy deserts are characterised by a low rainfall, and their general distribution is in general either on the leeward sides of mountain ranges or in valleys and plateaux between such ranges. In Northern Egypt the precipitation ranges from 0·27″ at Cairo, to 1·1″ at Suez, 2·1″ at Ismailia, 3·4″ at Port Said, and 8·1″ at Alexandria. In S. California and W. Arizona certain regions have a mean annual rainfall of less than 2″.

In the Karoo the precipitation varies from 8·65″ at Steotleville to 18·76″ at Graaff-Reinet (Buchan). In the Kalahari desert from 3·79″ at Pella to 41·10″ at Pilgrims Rest. On the West Coast of Africa from 2·11 at Port Nolloth to 8·37″ at Clan William.

Examples need not be multiplied; those quoted are sufficient to show that the amount is generally small and varies very considerably in different places. An equally important consideration is the *time* during which rain falls. If the precipitation is confined to one season and

for the rest of the year there is little or no rain, desert conditions may exist although the annual rainfall is comparatively large During the wet season the ground may be well watered, and streams of torrential size flow over the country, but the water is soon lost by percolation or evaporation and none is stored up to water the land in time of drought.

Vegetation is either very scant or absent, and the lack of vegetable mould diminishes the power of the soil to retain moisture. Professor N. S. Shaler (U.S. Geo. Sur. 12th Report) points out too that the absence of vegetable mould commonly causes the soil to present a dense baked surface which sheds rain like a roof.

In some places with very low rainfall the soil may be fertile owing to the proximity of mountains sufficiently high to nurse glaciers. The glaciers act as great storehouses and provide continuous irrigation during the dry season by the melting of the ice.

Streams of Desert Regions.

In South Africa during the dry season we often come across deep water-courses excavated during the time of the seasonal rains but now perfectly dry. Their beds are covered with well rounded boulders of such a size as to indicate that torrents must have flowed down the courses in order to move them. Towards the mountains the banks become steeper and loftier while in the direction of the plain the valley merges into the general outlines of the veldt, and at the junction it is marked by a spread of pebbles. In the Libyan and Algerian deserts similar water courses are found in the neighbourhood of their enclosing mountains. They are liable to floods of so sudden appearance and of such torrential violence that people engaged in gathering firewood, brought down by former floods, are sometimes overtaken and have no chance

of escape. At one time the bed may be perfectly dry and a moment later it is filled with a rapid stream hundreds of feet wide. In India these sudden floods are sometimes miles in width, they have no defined channel but flow like a sheet over the land.

During the dry season the sands blowing over the plains may fill up the dry channels and eventually all traces of the former water courses may be lost. In the next rainy season the streams descending from the higher grounds, may or may not flow in their old channels nor excavate to the same depth.

It is worth while at this stage to picture what kinds of deposits are being formed under the conditions just described. While the main portion will be composed of sand there will be included at various horizons, patches of gravel, lenticular in shape and of limited extent. I have seen sections through such deposits in a dry donga near Tintas Kopje in the Vryheid district and again in railway cuttings when traversing the Eastern desert of Egypt between Ismailia and Cairo. The pebble bands varied from a few inches to 4 or 5 feet in thickness and in my note book is an entry "exactly like our Bunter." However, we shall return to that later. I only wish at present to record the impression made on me at the time.

What Becomes of the Water?

The water flowing over the sand may be disposed of in three ways. (1) It may percolate under the surface; (2) it may be evaporated; (3) it may lodge in pools or lakes in places which are below the general level of the country.

1.—Percolation.

It has been known for a long time that under the dry, baked sands of the desert there commonly exists a great store of water, which only needs to be tapped in order to

be available for use. In the Sahara, artesian wells were sunk by the Greeks and Romans. In Algeria, a class of men called Meallem were formerly employed as water finders, and another class—the R'tassin—were engaged in the construction and cleaning out of wells. Their methods were primitive and involved great dangers. Since the French occupation more scientific appliances have been introduced and the fringe of fertile soil on the margin of the great Sahara is gradually being extended southwards. In sinking, the dry sand is penetrated until an impermeable clay or pan is reached. On piercing this the water rises, sometimes with sufficient force to reach the surface. The depth of the impermeable layer varies from a few feet to hundreds of feet and striking differences of level may be encountered in a short distance.

Tchihatchef* states that in the country of Honda, the well named Nemechdib is 10 feet deep, whereas the well Barika, almost close to it is 117 feet. Again at Batna and at Biskra, the soundings have been pushed through more than 540 feet, without reaching any subterranean water, so that the works were abandoned. He concludes from these facts that the clay is denuded "in the shape of high conical masses with hollowed basin-like tops." This supposes that one continuous bed of impermeable clay underlies the whole district, which seems to me unlikely and unnecessary as other explanations can be offered more in accord with desert features.

The condition of the water below the impervious bands must necessarily be largely a matter of inference. We naturally want to know whether it is stagnant or flowing, and whether it is carrying substances in solution and depositing these round the sand grains and thus cementing them into compact rock. If the water is

* Report, British Association, 1882, p. 357.

flowing, it must trend towards an outflow, and if this is restricted in area there must be definite lines along which the water runs. The stream lines will, under these circumstances, be convergent towards the outfall and the water outside the cone of flowing water may be stagnant.

That subterranean streams of fresh water do flow into the Red Sea from the desert is certain, and opposite their mouths the coral growth round the coast is interrupted. Some of these streams have been traced underground for great distances almost to the base of the Abyssinian mountains. The wells in the Oases, too, must be fed from the same source.

Similar lines of flow of percolating water can be traced in our local Triassic rocks. Sometimes they show themselves by a deeper staining, and in extreme cases the grains of sand have become so heavily charged with interstitial matter that they have formed pipes, the interior of which is dark brown or even black while the sand surrounding is almost white.

It would be unwise to assert that all the staining of our Trias took place at the same time as its deposition, especially in the case of those sandstones which are now above sea level. Where the beds are below sea level the staining must be prior to the movements which brought them to their present position, as no flow can take place from a lower to a higher level.

2.—Evaporation.

Another way in which the water flowing from the high grounds is disposed of is by evaporation. The amount of evaporation is largely dependent on the relative humidity of the air. Over the oceans the air may be approximately saturated, but in deserts the amount is commonly as low as 20 per cent. of the total capacity of the air to hold

moisture. At Assuan it is 38 per cent. for the year, varying from 29 per cent. in summer to 51 per cent. in winter. At Wadi Halfa the average for the year is 32 per cent.

When the air is not saturated, there is a constant exchange of water from the land to the atmosphere, and this results in evaporation at the surface and a creep of water from below owing to capillary action. Mineral substances contained in solution are disengaged from the water on evaporation at the surface and the soils in course of time become charged with saline matter. In this way the "sour" or "alkaline" soils have their origin.

The nature of the encrustation will, of course, depend on the composition and the amount of salts which the water holds in solution, and these again are dependent on the nature of the rocks over which the water passes. Potash and soda salts are common encrustations in some regions and they are often associated with the carbonates and sulphates of the alkaline earths. The former may be redissolved and partly removed in the rainy season, but the salts of the alkaline earths will be affected only to a very slight extent and will tend to accumulate. A very instructive example of this occurs in the dry donga near Vryheid mentioned above. Near the surface, the sands are coated with carbonate of lime. Sometimes there appear embedded in the sand roundish balls, ranging from the size of a marble to that of a man's head. In other places limestone of a compact texture and not enclosing sand forms a continuous layer on the surface of the ground.

In Rhodesia I saw natives clearing out ditches which run beside the railway in preparation for the rains, then almost due. These ditches were excavated in surface limestone and could be traced for scores of miles. Near Bulawayo limestones of this nature reach as much as 70

feet in thickness. In Las Palmas, Algeria and generally in deserts, similar crusts are found on the surfaces of rocks as well as on sand.

It is obvious that thick limestones of this nature cannot be formed by the creep of water from below. Once a continuous crust is formed the water is prevented from rising.

The probable origin of this limestone can be better discussed when dealing with desert pools and lakes, but it would be well to point out here that similar features to those just described occur in the Trias of Britain.

The potato stones in the south of England are exactly comparable with the nodules of Vryheid.

On Bidston Hill and West Kirby, in Cheshire, barytes occurs as nodules, and as bands encrusting sand grains, and the same mineral is found in the Trias of Nottingham and Staffordshire. The celestine occurring in the Trias about Bristol may have a like origin.

At Croft, near Leicester, a calcareous crust exactly resembling that found in deserts occurs on the surface of the underlying igneous rock and the covering Keuper marls are strongly impregnated with lime salts.

3.—Desert Pools and Lakes.

Looking across a vast expanse of desert the monotony of the scene tends to dwarf the sense of vertical height. With no outstanding features to rivet the attention of the eye the rolling dunes or naked rock give the impression of a level landscape. As a matter of fact the desert has its hills and its hollows, its crags and its ravines. In some of these hollows enclosed in a network of dunes or in rocky basins, water tends to accumulate and form pools or lakes. They may be fed by rain, by water percolating through the surface sand, or by streams flowing from the

hills. Often they have no outlet and then the water can only be lost by evaporation. They are full to overflowing when the seasonal rains fall, but during the long drought the waters gradually diminish, and in many instances totally disappear.

The water which finds its way into these pools or lakes brings with it matter in suspension and in solution. The former settles at the bottom as a fine mud. The mud, on drying, shrinks and forms the triradiate cracks characteristic of contracting sheets; it receives the imprints of animals' feet when they come to drink, and the impressions of rain when it falls.

The mud from the margin of a partially dried up vley at Riverton in South Africa shows all these features and in addition it contains vast quantities of the carapaces of *Estheria*, a tiny crustacean which has its proper habitat in such surroundings.*

The matter brought into the pools in solution will tend to concentrate as the water diminishes, and on complete drying, deposits of salt, gypsum and other salts will be left behind.

The salinity of the water will vary with the season.

Thus pools in the Rajputana desert in India are fresh for two or three months in the year. One constantly comes across contradictory statements in reading books of travel as to the salinity or otherwise of certain lakes. The observations may be right in each case if the travellers visited the lakes at different seasons of the year.

The occurrence of salt lakes in deserts is of the greatest interest and importance in the quest we have set before us. They are so characteristic of arid regions that it is essential we should have a clear impression of their peculiarities if we wish to make a true comparison with

* Habitat of *Estheria.*—Trias Report, British Association, 1905; and Monog. Palae. Soc., 1862, p. 57.

the rocks of the Trias. They have been described so frequently by travellers that I need only quote one or two examples.

Munzinger* in the "Narrative of a journey through the Afar Country," describes the great salt basin to the east of the Abyssinian mountains as bordered with walls of gypsum. Further, he writes: "The first part of the salt basin is sandy, but after a short distance, clay appears on the top, and every now and then we found a rain-ditch with powdered salt in it. After 1½ hours march we found a line of potasse trees, otherwise no tree or bush. The soil by degrees becomes of a greyish tint, and further on resembles a frosted ploughed field; but at the end the bed of salt becomes more thick and hard and presents the appearance of a lake frozen over."

Captain C. G. Rawling,† in exploring Central Tibet, visited numerous salt lakes. Of Gore Tso he writes: "A fine lake was seen two miles to the east, but mounds of some white mineral, piled up along the banks, almost certainly indicated that the water was undrinkable. Although this was the 5th of July, the lake was frozen from end to end. . . . On the following morning I made my way to the shores of the lake and found . . . all around rose a solid ridge of salt deposit, three to four feet high and from thirty to forty feet wide. No vegetation grew within 500 yards of the shores, while to the north a barren plain stretched away for many miles. The lake is about 20 square miles in area."

Sven Hedin writing of the Takla Makan desert states that the dunes are arranged in a sort of network pattern with hollows—or bayirs—inside the meshes. Clay rises as oblong terraces or steps 4 to 5 feet high along the slopes, giving the appearance of beach lines. The bottom of the

* Geog. Journal, 1869, p. 200.

† The Great Plateau p. 61.

bayir is covered with a granular hard incrustation of salt, at a distance resembling rime. Upon digging 8 or 9 inches a thick deposit of pure salt is reached evidently filling the bed of a desiccated salt lake, the margins and side terraces of which are coated with perfectly horizontal layers of yellowish-red clay 8 to 9 inches thick and hard as stone. In some bayirs a part remains moist and is edged all round with a narrow belt of salt. A bed of gypsum was observed in some cases, and one contained the skeleton of a water bird and a dead day-fly.

The above excerpts give one a good idea of what the desert salt lakes are like, and one or two facts common to all are worth noting. First, we have the clay bottom sometimes augmented in thickness by layers of sand which have drifted into the pool; then we note the constant association of salt and gypsum in the deposits. It is well known that concentrated brine precipitates the sulphate of lime out of solution. Further, we have no mention of carbonate of lime as one of the constituents left after evaporation, or, at least, if present it is not in sufficient quantity to call for special notice. Yet in the waters flowing from the hills towards the lakes this substance, as the bi-carbonate of lime, must have been present, and probably exceeding the others in amount. The explanation is simple. The bi-carbonate is chemically not a stable compound, and readily parts with the excess of carbonic acid. Hence in passing over or through the soils the carbonate of lime will be precipitated and form the nodules and limestones described above (p. 178) while the more chemically stable compounds will reach the lakes undiminished in quantity.

So it happens, as we should expect, that carbonate of lime segregates on the land while salt and gypsum are the chief substances left as residues in the desiccated pools. Dolomite in perfect rhombohedral crystals is

occasionally found in association with the products of desert pools.

Drifting sands blowing over the plains may fill up the hollows and leave no sign on the surface, of the pools which formerly existed there. The lake deposits would still be there buried under the sand, and if a section could be made through them we should find beds composed mainly of sand with thin bands of clay following the limits of the lake and irregularly disposed at various horizons. On the margins, the clay would show desiccation cracks and ripple marks, the footprints of animals, and the remains of such forms of life as find a suitable habitat under such conditions.

Mr. T. H. Holland,* referring to the deposits in the Rajputana Desert, states that silt beds occur, filling in hollows in the Archæan surface. They have a general plano-convex lens shape, and are charged with salt, beds of gypsum, and concretionary nodules of carbonate of lime.

In our Triassic rocks we get the exact counterpart of these filled-in desert lakes. Bands of clay occur in all the divisions, but they are more common in the higher beds. When the full extent of the clay bands can be determined, they are always half lenses in shape, with the convexity downwards. It is on the lower surfaces of the sandstones, immediately resting on the clay, that we find casts of footprints, raindrops, ripple marks and desiccation cracks, and the clays often either contain pseudomorphs of rock salt or deposits of this mineral and gypsum overlie the clay. The salt beds of Cheshire have these associations, and are now generally regarded as resulting from dried-up pools or lakes. Even when beds of pure salt are absent, it is found that water from the Keuper Marls is almost invariably strongly impregnated

* Brit. Assoc. Report, 1906, p. 575.

with salt. It may be that where beds of pure salt are found they have been covered by drifting sand after complete desiccation of the pool, and when the salt is intimately mixed with the rock, the wind-borne material was deposited in the pool while some water remained.

Dr. Cullis has recently described the occurrence of dolomite crystals in the Keuper Marls of the west of England. So far they have not been found in our locality, although carefully looked for.* We cannot say at present how these crystals have been formed, but their presence in recent deserts and in the Triassic rocks is of interest.

When dealing with the subterranean water supply of the desert, it was pointed out that the impermeable bands which confine the water below show very striking differences of level. If these bands of clay can be regarded as the silt covering the floors of filled-up pools, our difficulties are most satisfactorily met. (See p. 176).

Thus far we have dealt with the part water plays in the economy of the desert. The waste of sand stretching as far as the eye can reach gives little sign of the activities below the surface, and it is chiefly there that water has its work to do.

Surface Deposits.

We turn now to discuss the surface deposits themselves. It must not be supposed that even in the so-called sandy deserts, the surface is uniformly covered with loose fragmentary materials. In the Algerian Sahara probably less than one-third is covered with sand. Solid rock forms the floor of vast barren plains, or stands as islands or cliffs washed by great seas of sand. However, it is mainly with the sand (and in this term we may for convenience include pebbles) that we have to deal.

* It might be noted that dolomite occurs in plenty in the sands dredged from the Mersey bar.

Origin of the Sand.

The sands of the deserts were naturally at first attributed to marine action, and the presence of salt deposits no doubt gave verisimilitude to the idea that they represented dried-up sea-bottoms.

Zittel, Tissandier and others have shown that the fragmental material is of subaerial origin and has been derived by the action of the ordinary disintegrating forces at work on the land.

In a climate such as ours it is hard to appreciate the importance of one of the most important disintegrating agents in the desert. One needs to stand under the tropical sun and in the presence of the riven rocks to fully appreciate what sun-flaking means.

Unprotected by vegetation or covering soils the bare rocks become intensely heated during the day; when the sun's heat is withdrawn they rapidly chill by radiation, and thus by alternate expansion and contraction even the most compact and resistent rocks yield.

A characteristic form assumed by sun-flaked rocks is the spheroid, and one is reminded of the spheroidal weathering often seen in basalt. In a cuboidal mass of granite the solid angles are the first to split, and then the edges go, and so, flake after flake is removed until the block resembles a well-worn boulder.

The flakes are usually from half an inch to a little more than an inch in thickness, but their horizontal extent may be many yards. After flaking, the smooth curved surfaces give one the impression of roches moutonnées when viewed at a distance and individual spheroids resting on these surfaces resemble perched blocks. At the foot of a cliff screes of angular flakes tend to accumulate. These still further break up under similar influences and finally form sand. They may

accumulate until the rock is buried under its own fragments, or in the rainy season the loose material may be carried away to form sandy deltas, and the surface of the solid rock may be kept open for further flaking. Sands resulting from the disintegration of granite and other rocks in the desert are in striking contrast to those formed in our own country in so much as chemical action takes no part in the breaking down of the rock. The fragments are chemically unaltered and the flaked surfaces consist of perfectly fresh minerals. Of course in the neighbourhood of mountains, sufficiently high and conveniently situated to intercept moisture-laden winds, both chemical and mechanical disintegration may take place and streams may flow into the lowlands mingling water-borne material with that of desert origin.

It is difficult to apply the tests of sun-flaking and the characteristics of desert sand to our Triassic deposits as so few places exist where they are seen to lie on the rocks which gave them their origin. However, in the neighbourhood of Leicester, in Charnwood Forest, on Mount Sorrel at Croft and at other places where the Keuper rests on the igneous rocks we get the very best conditions for making the comparison. Professor W. W. Watts has shown that in this district the Keuper fills up hollows in the older rocks and denudation is now uncovering the old pre-Triassic landscape. The older rocks, particularly at Mount Sorrel, present curved flaked surfaces exactly like those described from the desert. Loose blocks are flaked into spheroids and lie tumbled in the Keuper Marls which must have been accumulating at the time the blocks fell from the cliffs above. Screes of angular flakes rest against the ancient slopes and the sand is composed almost exclusively of material from the adjacent rocks. Moreover, the surfaces of the rock, the scree material and the sand are all chemically fresh.

The absence of decomposition products is well seen, too, in the Keuper sandstones of our own neighbourhood in places where infiltration has not taken place. When a clay band occurs in a rock face, the felspars in the top portion are usually kaolinised by the percolation of surface waters, but below the impervious layer they are remarkably fresh. This conclusively demonstrates that when they were laid down they were not subject to chemical changes.

Work of the Wind.

During the dry season the wind does its own work in carrying, sifting, rounding and etching.

1.—Carrying.

In open ground driven sand tends to accumulate in ridge-shaped masses, the long crests lying transversely to the wind. When a dune of this kind has been originated the wind blows grains up the exposed slope and over the summit where they drop on the leeside. The slope to windward is gentle and on the leeside steeper and slightly concave. The concavity is due to a backward eddy which sets in as the wind passes over the crest, and can easily be demonstrated in our local sand hills by putting a piece of paper or any light object against the leeward slope when a stiff wind is blowing. The paper will be seen to move up the slope against the wind.

In our neighbourhood the dunes seldom exceed 50 feet in height, but in the desert they have been measured up to 350 feet. A favourite simile with travellers is to compare dunes with the waves of the sea, with crest and trough following each other in parallel sequence or arranged in a network pattern.

One fundamental difference must be kept in mind; in the sea the wave motion progresses while the material is

stationary. In the desert the sand travels with the wave movement. The Arabs say that the dunes "walk." It follows, then, that if the material goes forward the country to windward will be left bare unless fresh material is forthcoming from that quarter. Deposits accumulated by wind action show very characteristic false bedding. The nature of this depends on the steepness of the slope over which the sand tumbles and the varying directions of the wind. When the slope to leeward is very steep the weight of the sand at the top may cause the sand to slide down into the hollow, thus puckering and folding the layers beneath.

The distance to which sand may be carried by wind is very great. Dust storms are sometimes met with in the Mid-Atlantic which can only have come from the western Sahara. At Las Palmas a ridge of sand dunes exists on the low isthmus connecting the Port with Isleta. The rocks of the island could not yield such a deposit, and captains of ships attribute the sand to winds blowing from the African continent. The finest sand dust may be carried in the air for hundreds of miles, and when the winds are constant the result will be the building up of thick masses of stratified material. Such is the origin attributed to the Loess of China which attains more than a thousand feet in thickness, and Richthoven supposes it to have come from the desert areas of Asia. Professor N. S. Shaler* assigns a similar origin to the accumulation of fine-grained detritus in the Western Mississippi Valley and he states that it has been derived from the Cordilleras.

2.—Sifting.

The sifting action of wind may be observed in a dusty road or in our local sand hills. In deserts, however,

* U.S. Geol. Survey, 12th Report.

where the winds blow more consistently from one quarter, the action is more perfect.

A series of specimens obtained from the Sahara by the late Dr. Isaac Roberts, and presented by him to the Liverpool University very strikingly illustrate this fact. They represent a series of samples taken from the same locality in vertical sequence. The grains differ in size at each horizon, but for the same depth the sifting is so perfect that it looks as if each sample had been put through a sieve. Many other observers have commented on the sifting action of wind, and it is only reasonable to suppose that the size of grain carried along will vary with the velocity of the current which moves it.

Sven Hedin graphically describes a sandstorm he encountered in Central Asia. Near the ground the wind velocity was $40\frac{1}{2}$ miles an hour. Six feet from the ground it measured $58\frac{1}{2}$ miles an hour. Branches, tufts of grass, and grains as big as peas whirled in the air and struck his face with stinging force.

A strong wind such as that described will move large and small particles alike, but as it loses velocity the particles will drop to the ground as the carrying power of the wind diminishes. Thus the sands raised by one storm will be graded horizontally, gradually getting smaller to leeward.

The same sands may be worked up again and again by currents of differing velocities, and hence we should not expect to find the layers of even-sized grains to persist over very great distances. Again the grains are not all composed of materials having the same relative density. Although quartz predominates, we find mica, felspar, magnetite, zircon and other minerals, and each will be affected according to its linear dimensions and specific gravity.

If we consider two particles of different sizes and having the same terminal velocities when falling under

gravity we find the resistance varies as the square of the linear dimensions and the weight jointly as the cube of the linear dimensions and the specific gravity. This is only a very simple and incomplete way of stating a very complicated problem, but it is possible to find in terms of their relative densities and dimensions the sizes of the different kinds of grains which will come to rest together.

We have already seen that where temporary streams flow down from high grounds, fans of gravel are produced where they debouch into the plain, and along the beds of water-courses there exist layers of gravel, composed of water-worn stones. The distance these stones have travelled from their place of origin depends on the character and volume of the stream which brought them. It may be reckoned in miles or scores of miles. We pictured above (page 175) the character of the deposits formed by the successive excavation and filling up of river valleys and gave instances where sands with bands of pebbles intercalated at various horizons had resulted from this action. What is the effect of winds blowing over a deposit of this nature? The sands are carried by the air currents and form dunes, but the larger stones are too heavy to be moved and form a loose pavement on the desert floor.

According to Mr. H. T. Ferrar, of the Geological Survey of Egypt, these pebble layers may be so thin that the tread of a camel may break through and send up puffs of the sand from below at every step. At other times they are more than 100 feet thick. These may result either from excessive rainfall and strong currents of water or from the successive accumulation of materials brought down by streams through many wet seasons, and the removal of the finer material during many dry seasons. In any case we have in deserts great spreads of gravel brought down by rivers and re-assorted by wind action.

3.—Rounding and Etching.

Sands caught up by the wind and hurled against each other have a greater velocity and hence a greater impact than those carried along by moving water. In river and sea sands rounding does take place but it does not approach the perfection seen in sands which have been subject to prolonged movement in air.

The constant battering of grains against each other not only results in rounding, but in the production of excessively fine splinters of sand. It is this sand dust which is carried to great distances by winds and tends to accumulate on the lee sides of desert regions.

Particles too heavy to be lifted bodily in the air are rolled along the ground. If it happens that the length of a grain is great as compared with the width the rolling may be confined to one axis of revolution and a cylindrical form results. Cylindrical grains of this nature are not uncommon in desert sands and they are found in the dunes round our coasts. The sands rolling up a slope often form the most exquisite ripples giving the appearance of tiny dunes riding on the larger ones. Perfect spheres do not, as a rule, result from the attrition of very small grains, and we seldom find "Millet seed" sands with a diameter of less than ·5 mm. Not only does abrasion take place by the striking of one grain against another but the battering of grains against the solid rocks or against loose stones lying on the surface of the desert results in some characteristic effects. The effects produced on the rocks will vary not only with their hardness and texture but also with the angle at which the impact takes place.

A glass tumbler dropped by a tourist in the desert was found after a time to be frosted and opaque on those parts exposed above the sand. It exactly resembled the sand

blast labels on our reagent bottles and the designs frosted on glass intended for ornamental purposes.

Blocks of obsidian found in the deserts of Iceland likewise become frosted on their exposed surfaces. Granite on the other hand takes a beautiful polish. If the rocks contain minerals of varying hardness the softer constituents tend to form hollows, while the harder materials stand out and are sometimes completely disengaged from the mass. In this way the fossils in the nummulitic limestone of which the Great Pyramid is built, stand out from the surface and large numbers of loose nummulites can be found in the sands surrounding the base of the pyramid. So perfectly and so intimately does the sand pick out the parts of superior hardness, or of looser texture, that pieces of silicified wood can be found in the neighbourhood of Cairo with the vascular fibres standing out from the less compact parenchymatous tissue.

Mr. W. D. Brown* quite recently described before this Society some most interesting experiments which he performed with artificial sand blast on various rocks. He showed that a blast with a pressure of 45 pounds to the square inch acting perpendicularly on sandstone drilled a cylindrical hole and removed 435 grains in 5 minutes, whereas the same blast acting on the same piece of rock at an angle of 45 degrees produced an even plane surface and only removed 400 grains in ten minutes. A piece of granite with an oblique blast lost 200 grains in 5 minutes, while limestone lost 323 grains in the same time and under similar conditions. All the stones subjected to the experiments possessed rounded surfaces before being acted upon, but the sandstone and limestone were reduced to plane surfaces while the granite showed differential action, the quartz standing out from the softer constituents.

* Proc. L'pool Geol. Soc., Vol. x., p. 130.

The production of a plane surface by oblique sand-blasting may be compared with the action of a file drawn over a curved surface. Being rigid, the file moves in a straight line, it does not accommodate itself to the outlines of the substance, but produces a sharp cut edge where it leaves the object. Similarly sand moving with great velocity keeps its initial path while similar particles moved slowly by a current of water over a curved surface would roll over the leeward slopes and abrade during their descent. It must not be concluded that a plane surface can only be produced by the action of wind-driven sand. In Switzerland I have seen plane surfaces and sharp cut edges, produced in the beds of torrents carrying sand in suspension, quite indistinguishable from those produced by wind action. The plane surface then is largely a result of high velocity, and while this is of rare occurrence in currents of water it is common in currents of air.

When driven sand strikes a stone in the open desert it is deflected upwards and round the sides so that plane surfaces are formed on three planes. This is the typical form to which the name dreikanter has been applied, and the finding of these in any deposit is regarded as one of the surest indications of wind action.

Sand blowing over a flat surface of rock tends to widen joints and open them out into a funnel shape, with the wide end facing the direction of the wind. The sides of the opened joints, too, are almost invariably undercut.

It has been shown by Professor Watts, Mr. Walcot Gibson and others that the surface of the country had been carved by denuding forces into valleys and hills before the Trias was deposited. The newer rocks by filling in the low grounds smoothed down the landscapes and in some places hills were completely covered. In no part of Britain do Triassic rocks attain a greater altitude than 800 to 900 feet above sea level at the present

day, and we have no proof that they ever extend much above this level. They are essentially deposits of the lowlands. Their distribution has been admirably summarised by Professor Bonney,* and I can add nothing to his lucid description of their occurrence. He shows that there exist two foci of coarse fragmental rocks, one in the western and northern Midlands, and the other in Devonshire. No one now doubts that Professor Bonney is right in claiming these coarse deposits as of fluviatile origin. At the places mentioned, rivers reached the plains (whence they came does not matter at present) bringing down pebbles, well worn in transit, and no doubt a large amount of finer material as well.

Taken as a whole the deposits get finer as we go away from the foci, and on the extreme borders of the areas covered by Trias they consist of exceedingly minute fragments. At a subsequent stage in the history of the Trias, pebbles occur again, indicating a return to the conditions under which the lower beds containing pebbles were formed.

Assuming that desert conditions prevailed during Triassic time—interrupted, perhaps, by pluvial periods, when rapid streams brought down the pebbly constituents—let us see how far they show evidence of the action of wind. Except in the finer deposits such as the Keuper Marl true bedding is almost entirely absent. Current bedding there is in plenty, and frequently very steep, too steep, indeed, for the angle of rest of sand laid down in water. In extreme cases of steep false bedding the sands are often contorted at the bottom of the basin as though the weight of the sands above had caused a slide such as we have described as taking place in sandhills.

It is difficult to describe the structure of the sandstones; there are no geological terms exactly suitable. They

* On the Origin of the Trias, Proc. Yorks. Geol. Soc., Vol. xvi. (1906), p. 1.

have the appearance of a tumbled series of eroded lenticles. Anyone who has had the misfortune to map them, knows how the beds thicken and thin out promiscuously, and how difficult it is to find a datum line which will be of service in correlation. Even our late member and founder, Mr. Morton, whose knowledge of our local rocks was so intimate and extensive, would never give an opinion as to the horizon of a piece of Trias sandstone from a hand specimen. The only approaches to satisfactory datum lines we possess are the two horizons where pebbles occur, and even these are only of service locally as they are limited in extent. In sections cut through dunes in the desert between Ismailia and Kasassin, I have seen beds very much resembling those I have attempted to describe above.

The marginal beds of the Trias area are almost without exception the Keuper Marls. They are found also covering the sandstones in the middle of the area and sometimes they are intercalated with beds of sandstone. They are not strictly marls, but are composed almost exclusively of exceedingly fine and angular quartz dust. It has been suggested that they have been laid down in a lake, or a series of lakes, and the even bedding which they show is given as a proof. But bedding even more perfect may be seen in volcanic dust deposited on the land, and further Mr. T. O. Bosworth has shown that when the Keuper Marl rests against a sloping cliff, the bedding slopes with the surface of the ground. This is quite unlike the conditions we should expect to find if it had been of subaqueous origin. Lakes of the desert type are found as local phenomena in the Keuper Marls and have been referred to in a previous part of this paper. The marls may represent the smallest tailings of wind-carried material.

The sifting action of wind is everywhere evident

in the Trias. Besides the horizontal grading already mentioned which characterizes the deposits broadly as a whole, we find that locally the same sifting influences have been at work. Sands of exactly the same dimensions occur as lenticular patches, a few feet or several yards in length. These are associated with other lenticles of larger or smaller grain, but in the same patch there is no admixture of large and small sizes. In our neighbourhood they are best seen at the top of the Bunter, immediately underlying the Keuper basement bed. The perfection of sifting into sizes shown at Bidston and at Scarth Hill is marvellous, but in other places and at other horizons the same features may be observed.

The concentration of pebbles from river deposits is also paralleled in the Trias. The pebble beds of the Midlands although originally of fluviatile origin do not exhibit the characteristics of river action. The individual pebbles show no orientation in the arrangement of their longer axes, but are wedged together in a tumbled mass as if they had dropped into their present situations by the removal of material about them. The insecurity of their positions is evidenced by the pitting which has resulted from their successive readjustments. The interspaces between the pebbles are almost free from sand, but lenticular seams of sand occur, which may have been protected from removal by wind, when the pebbles formed a continuous covering. There are places in our own district where it does not appear that concentration took place, and the sand with pebbles marking the situations of temporary streams still persist as originally laid down.

The occurrence of millet seed sands in the Trias is too well known to need further comment, and they have always been attributed to wind action. Professor Watts,*

* Geological Journal, 1903.

too, has shown that the surfaces of the Mount Sorrel granite, when freshly uncovered from the mantle of Trias, show very characteristic wind etching, and at Croft the underlying igneous rocks have their joints widened and their vertical faces undercut in a way that could only be produced by wind. Dreikanter occur sparingly in the pebble deposits. They are not common even in recent deserts, for only the surface pebbles can come under the influence of the wind.

Conclusion.

In conclusion I may once more state that the chief object in view in writing this paper has been to institute a comparison between the features and activities of existing deserts and the Trias rocks of our own country.

It is not intended as a description of the Triassic rocks themselves. The question has been discussed entirely from the physical standpoint. The palæontological aspect still remains to be considered. The animal and plant associations, and their adaptations to the peculiar circumstances under which they live in the desert, should find their counterparts in the Trias, if arid conditions existed during their formation.

Although material is rapidly accumulating regarding the fauna and flora of the Trias, it must be acknowledged that we know too little to make useful comparisons, and we must wait for fuller information both in respect to the life of the Trias and the life of existing deserts.

ANALYSES OF LUDLOW ROCKS,

By T. Mellard Reade, F.G.S., F.R.I.B.A., and

Philip Holland, F.I.C.

A month spent in the neighbourhood of Ludlow, Shropshire, during the summer of 1906, suggested to us that a series of analyses of the Silurian and Old Red Sandstone might have some value in the geological interpretation of these formations.

With this end in view, what were considered to be typical examples of the strata were collected and a selection made from them for analysis.

The series is arranged in sequence, commencing with the Old Red Marl and working down to the Silurian. The basalt of Clee Hill, intrusive in the Carboniferous, was also analysed.

In the following pages each rock specimen is described, its structure and physical peculiarities noted, and analyses given.

After a due consideration of all these details an attempt will be made to briefly point out the way the chemical and mechanical constitution of the rocks have influenced the physiography, scenery and vegetation of the country.

The probable conditions under which the sediments were accumulated will also be touched upon.

We desire here to express our indebtedness to Mr. Charles Fortey, Hon. Curator of the Ludlow Museum, for the assistance kindly rendered during the prosecution of our work.

DESCRIPTION OF THE SPECIMENS.

No. 1.—*Old Red Marl from near cutting at Bitterly, Ludlow, and Clee Hill Railway.*

A quite fine deposit. Did not contain any stones or coarse gravel. The specimen weighed 7 ounces and was easily crushed by pressure alone.

No. 4.—*Old Red Marl from Targrove Quarry.*

A weathered surface specimen. Fragments of shell were noticeable on the 30-mesh sieve, but they were not very numerous. In No. 1 they were not seen on the 30-mesh sieve, but were probably present, for the analysis of No. 1 shows some carbonate of lime. Ligneous matter was visible on all the sieves in the case of No. 4. Not so in the case of No. 1.

No. 5.—*Old Red Marl from Sheffield and Turner's Brickworks below East Hamlet.*

A compact specimen of greenish grey mudstone much stained in places by red marl. It was slightly fissile, and the surfaces showed glistening flakes of mica. Weight of specimen $1\frac{1}{4}$ lbs. It was easily crushed by pestle blows, though not by considerable pressure. All crushings passed the 90-mesh sieve save a few grains of clear quartz and flakes of mica. Particles of shells were not detected with a lens in the siftings of this specimen.

No. 7.—*Old Red Marl from Sheffield and Turner's Brickworks below Greenfield.*

This specimen was a slab of compact gravel and grains of sand. It held numerous oblate smooth concretions much redder in colour than the slab itself and easily detachable from the interior layers. One of the concretions weighed $\frac{1}{2}$ oz. The concretionary matter is more aluminous than that of the slab. The concretions were easily crushed and revealed very fine mica on fractured surfaces. The material composing the slab effervesced

freely with acid, whereas that of the concretions did so but slightly. We give analyses of the sandstone slab, also of the enclosed clayey concretions. No particles of shell were visible in this sandstone. The general appearance of the specimen would suggest that small balls of clay had got included in the material of the sandstone before consolidation. Amongst the grains of sand were spherical grains, also some deformed quartz hexagons.

The average size of the largest quartz flakes across longest diameter was 0·20 mm.

These old red marls although used for brickmaking contain, as the analyses show, only small quantities of clay. When collecting the specimens it was seen that the marls have intercalated sandy layers. All these beds, sandy or otherwise, are ground together for brickmaking. The bricks used about Ludlow are made from these marl beds.

No. 10.—*Micaceous Old Red Sandstone from Quarry 1 mile from Bromfield Station.*

The specimen was in small pieces, grey in colour, with abundance of small mica. Quite gentle pressure crushed the whole, so that all passed the sieves save a little which the 120 mesh retained. The average size of the largest grains so retained was 0·30 mm., but grains of this diameter were few.

SILURIAN.

No. 13.—*From a Quarry of Aymestry Limestone at Hay Mill, near Ludlow.*

A dark blueish grey hard rock of very fine texture. This specimen had an adherent patch of calcite, which was removed before crushing the limestone, which was easily done without any grinding. A small fragment put in cold HCl soon became disintegrated, setting free particles of angular and rounded quartz, of which slides were prepared. The mean diameter of 10 of the largest flakes

on the slides was 0·12 mm. On the slides were one or two deformed quartz crystals. These crystals are well represented in the Buxton limestone. Indeed, the residue of the Buxton* limestone insoluble in HCl almost consists of well-shaped quartz crystals along with a little ferruginous clay and organic matter.

No. 16.—*A Specimen from the Bone Bed, Ludlow, collected by C. Fortey, Esq.*

This was a slab of greenish grey mudstone of very fine texture. It was $1\frac{3}{4}$ inches thick and weighed $8\frac{1}{4}$ ounces. On one surface were embedded dark glossy rod-shaped bodies. The surface also showed casts and pittings of these and other forms. The fossil surface was darker than the rest of the slab and had a thickness of 2 mm. With care we were enabled to remove some of the fossil layer. This and a portion of the mudstone itself, cut off $\frac{3}{4}$ of an inch below the fish remains, were separately analysed. The analysis of the subjacent portion was made to trace infiltration of carbonates and phosphates from the bone bed, which in so porous a rock might easily have come about.

No. 17.—*Upper Ludlow, from Quarry by Upper Bridge.*

A grey mudstone of very fine texture. On one surface are casts of bivalve shells, but no shell particles visible with a lens. This surface was rasped with a file and the powder collected. A portion of the mudstone nearest the shell casts after they had been completely rasped away was also examined.

No. 18.—*Upper Ludlow, by Upper Bridge, near same locality as No.* 17.

A dark grey rock. The specimen weighed $7\frac{1}{2}$ ounces and was 1 inch thick. The upper and lower surfaces were

* Specimens from other localities in Derbyshire have not yet been examined for these crystals to see if their occurrence be general.

much pitted with shell casts and had valves of shells still *in situ.* The largest perfect valve was $4\frac{1}{2}$ mm. long. A smaller one measured $2\frac{1}{2} \times 2$ mm.

No. 19.—*Woolhope Limestone, collected near Wigmore.*

A fine textured, very hard, grey rock. The specimen weighed 12 ounces. On breaking it up fragments of fossilised shells were noticeable, but the fragments were few. One flat dark valve turned up at the first blow of the pestle and shone as though polished with graphite. The flutings showed very distinctly. On the longer axis it measured 4 mm. The valve was unfortunately broken in cutting away the enclosing rock. A small piece of the rock was placed in hydrochloric acid, in which in time it became disintegrated. Slides of the sandy residue were prepared and measurements made of ten of what appeared to be the largest of the grains of quartz. The average size across the longest diameter was 0·09 mm. The grains were mostly flaky, with rounded edges. Flakes smaller than above had sharp edges. Flakes so large as 0·09 mm. were few on any slide.

No. 20.—*The Clee Hill Basalt from Eastern Quarry.—Post-Carboniferous.*

A very hard crystalline, almost black rock of fine texture. Contains magnetite and here and there a mere speck of pyrites. Sp. Gr. 2·890.

Notes on the Scheme of Analysis of Marls, Clays and Sandstones.

During the past year several correspondents have sought information on our scheme for analysing clays and marls. In Part III. of "Sands and Sediments" an outline of the scheme is given. For the work of our present paper the same general plan has been adopted, but hydrochloric has been substituted for sulphuric acid extraction. The weight of very finely powdered and dried

material taken for analysis is 5 grams. The volume of acid (40 cc.), the duration of the extraction, and temperature, have been alike for each specimen. Attention to these points is imperative, for it has been found that longer digestion or higher temperature slightly increase the amount extractable by acid from one and the same clay.

This will be understood on reflection, for some mineral silicates in clays yield less quickly to attack than others, though they do yield gradually if the acid attack be prolonged or the temperature be raised.

A correspondent, Dr. E. W. Hilgard, objects to the use of caustic soda for dissolving from the residue the silicic acid set free in the acid extraction. Dr. Hilgard considers that soda will have a strong solvent action on the ever present quartz dust and its use will on that account tend to vitiate the figure for silicic acid. Lunge and C. Millberg (Zeits. Angew. Chem., pp. 393 and 425, 1897), call attention to the solvent action of soda (NaHO) on fine quartz, but employing, as they did, a dilute solution, regarded the action as almost negligible. We ourselves have lately gone into the matter. When 5 grams of finely powdered and elutriated Brazilian quartz was heated in the steam bath for five minutes with 100 c.c. of a 3 per cent. solution of pure NaHO we obtained the following percentages for quartz dust dissolved, viz.:— 0·37, 0·28, 0·31, 0·32; average, 0·32. Now, inasmuch as 5 grams of dried and powdered clay, or marl, will never contain so much impalpable quartz as must have been present in the above test experiments, the correction for quartz soluble in soda will fall well below 0·2 per cent. In Part III. of "Sands and Sediments" (Pro. L'pool Geo. Soc., 1905-1906, p. 145), we omitted to state that just 100 c.c. of the 5 per cent. NaHO was taken for an extraction and that the duration of extraction was then, as now, five minutes.

Test experiments on 2 grams of air-dried silicic acid prepared from sodium silicate in the usual way, have shown that 100 c.c. of a 3 per cent. solution of NaHO dissolved the whole in less than two minutes at a steam heat. Thus, taking 5 grams of a clay we see that 100 c.c. of the above would be ample and quite equal to the removal from the residue of 40 per cent. of silicic acid were so much ever set free by the HCl treatment. We trust the explanation of our *modus operandi* will reassure our experienced and courteous correspondent.

Dr. Hilgard has lately published a work entitled "Soils" (Macmillan), which treats comprehensively of soil characteristics, the geological origin and chemical peculiarities of soil, as also of the physical behaviour of its particles when suspended in water. Those desirous of studying soils from the agricultural standpoint will find in Dr. Hilgard's book much both to interest and to profit them.

ANALYSIS OF THE LUDLOW MARLS.

No. 1.—BITTERLEY OLD RED MARL SIFTINGS.

		Average size of largest grains.
30 Mesh Sieve retained	6·28	2·04 m.m.
60 ,, ,,	0·53	—
90 ,, ,,	0·36	—
120 ,, ,,	1·41	—
Not retained	91·42	0·21 m.m.
	100·00	

No. 4.—OLD RED MARL, TARGROVE QUARRY.

		Average size of largest grains.
30 Mesh Sieve retained	4·52	1·38 m.m.
60 ,, ,,	2·12	—
90 ,, ,,	1·51	—
120 ,, ,,	0·93	—
Not retained	90·92	—
	100·00	

THE 18-HOUR SUSPENDED MATTER.

No. 1	6·14 per cent.
,, 4	7·15 ,,

OLD RED.

	No. 1	No. 4	No. 5	No. 7*f*	No. 7*a*	No. 10
Combined Water and difference	5·61	7·08	3·87	2·94	4·41	4·38
Insoluble in Acid and Alkali	58·74	54·37	73·94	73·26	61·12	77·23
Soluble in Acid and Alkali	—	—	—	—	—	—
Silica, SiO_2	11·95	14·77	8·90	6·32	13·38	7·42
Titanic Oxide, TiO_2	0·15	0·25	0·16	0·20	0·24	0·15
Alumina, Al_2O_3	6·10	7·35	5·19	3·44	8·41	4·46
Ferric Oxide, Fe_2O_3	5·14	5·00	3·51	4·25	7·33	2·66
Ferrous Oxide, FeO	—	—	present	present	none	1·07
Manganous Oxide, MnO	0·10	0·12	present	0·08	0·12	0·05
Lime, CaO	5·60	4·69	1·32	4·76	0·90	0·28
Magnesia, MgO	2·42	2·04	1·98	1·07	2·86	1·70
*Potash and Soda, Alkalies	0·70	1·27	0·60	0·38	0·95	0·56
Carbonic Acid, CO_2	3·44	2·98	0·53	3·10	0·14	none
Sulphuric Acid SO_3	—	—	—	0·04	none	none
Phosphoric Acid, P_2O_5	0·05	0·08	trace	0·16	0·14	0·04
	100·00	100·00	100·00	100·00	100·00	100·00

No. 7*f*.—The Sandstone. No. 7*a*.—The Clay concretions in No. 7. * Soda slightly predominates in some of the specimens.

SILURIAN.

	No. 13	No. 16	No. 16*a*	No. 17†	No. 18
Combined Water and difference	3·11	4·05	4·80	3·36	3·50
Insoluble in Acid and Alkali	45·58	16·70	70·69	66·07	75·45
Soluble in Acid and Alkali	—	—	—	—	—
Silica, SiO_2	4·04	2·14	10·45	6·25	7·99
Titanic Oxide, TiO_2	0·06	0·07	0·08	0·10	0·07
Alumina, Al_2O_3	1·11	3·87	6·30	3·27	4·15
Ferric Oxide, Fe_2O_3	0·51	2·47	2·66	1·37	2·81
Ferrous Oxide, FeO	1·79	present	1·79	1·27	1·42
Manganous Oxide, MnO	0·07	present	0·09	0·10	0·12
Lime, CaO	23·55	39·18	0·54	9·58	1·17
Magnesia, MgO	1·66	0·44	1·95	1·13	2·17
Potash and Soda Alkalies	0·52	not sought	0·51	0·66	0·55
Carbonic Acid, CO_2	17·94	10·95	none	6·72	0·50
Sulphuric Acid, SO_3	present	0·51	none	none	none
Phosphoric Acid, P_2O_5	0 06	19·62	0·14	0·12	0·10
	100·00	100·00	100·00	100·00	100·00

No. 16.—The layer of fish remains. No. 16*a*.—The underlying Sandstone. † Taken ¼ inch below the shell casts.

SILURIAN.

No. 19.—THE WOOLHOPE LIMESTONE.

Carbonate of Lime	64·47
Sulphate do.	0·40
Phosphate do.	0·10
Magnesia	0·09
Oxide of Iron and Alumina	1·72
Insoluble *in cold dilute HCl. (dried at 120° C.)* ...	33·40
	100·18

Some 10 grams of the insoluble in *cold dilute acid* was next prepared, which, after washing and drying at 120° C. was analysed on the same plan as the marls.

ANALYSIS OF THE INSOLUBLE IN COLD DILUTE HCL. OF THE WOOLHOPE LIMESTONE DRIED AT 120° C.

Combined Water and difference	4·75
Insoluble in acid and alkali	78·52
Soluble in acid and alkali:—	
SiO_2	7·48
TiO_2	0·13
Al_2O_3	3·69
Fe_2O_3	0·99
FeO	1·97
MnO	present
CaO	traces
MgO	1·93
Alkalies	0·54
	100·00

This sandy residue occluded in the limestone approximates closely in composition to No. 10 sandstone, but the two rocks are of different geologic age.

No. 20.—THE CLEE HILL BASALT.

Total SiO_2	50·23
ZrO_2	0·02
TiO_2	1·20
Al_2O_3	17·16
Cr_2O_3	0·07
Fe_2O_3	2·44
FeS_2	0·09
FeO	5·46
MnO	0·19
CaO	8·10
BaO	0·06
MgO	6·23
K_2O	1·94
Na_2O	4·23
P_2O_5	0·15
CO_2	0·03
Combined Water	2·13
	99·73

This analysis in some respects resembles that of a greenish black dense basalt from Rio Grande Canyon, New Mexico, given on p. 184 of the Bulletin of the United States Geological Survey, No. 148. 1897.

The search for ZrO_2, Cr_2O_3, BaO was made on 8 grams of the Clee Hill specimen. The object was a comparison of our specimen with the basalts and andesites of the United States, in which these oxides sometimes occur, the Cr_2O_3 often associated with much MgO in certain specimens.

DISCUSSION OF THE ANALYSES OF THE LUDLOW MARLS AND ADJACENT ROCKS.

The marls and sandstones are all of fine texture, and most of them so loosely compacted as to be reducible to powder by pressure or by gentle blows. The colour varies from a chocolate brown to a greenish grey shade. Those

of a greenish hue still contain much of their iron as ferrous oxide, to which their greenish shade is chiefly due. Most, if not all, contain carbonate of lime in varying amount, as the figures show. In some instances shell fragments, as in No. 4 marl, were visible without a lens. In No. 5 there was effervescence but no shell stuff visible. No 7 effervesced with acid, but the effervescence appeared to arise from the surfaces and at conjunctions of sand grains, which would indicate deposited calcite. No. 10 is lime-free, which may indicate perfect leaching by water or original absence of any shell matter from the deposit.

Reverting to No. 1, we consider this to be a typical old red marl. The amount of fine textured material, viz., 91·42 per cent. which passed so close a mesh as 120 wires to the inch, is striking. The sub-division of the materials no doubt tends to confer on these marls the good agricultural qualities they are known to possess.

The total alkali in No. 1 marl is 1·98 per cent., of which $\frac{7}{10}$ths of a per cent. was extractable by acid. The carbonate of lime is 7·8 per cent., but there is also lime belonging to the calciferous minerals of the sand. A little phosphate of lime occurs in most of the specimens. No. 4 shows 6·8 per cent. of carbonate of lime. The total alkali in this specimen was determined and found to be 3·26 per cent., of which the acid removed 1·27 per cent. The alkaliferous mineral of this marl would thus appear to be more readily attacked by acid than that of No. 1. The higher yield of alkali in No. 4 may be explained by greater weathering opening up the marl and thus initiating decomposition of the felspars *in situ*. Weathered rock for this reason may be expected to yield its alkali more readily to acid extraction than sound rock.

The carbonate of lime in No. 5 is 1·2 per cent., with phosphate absent. No. 7 specimen has 7·0 per cent. of

carbonate and slightly more phosphate of lime than Nos. 1 and 4. In No. 7*a* (the clay concretions enclosed in No. 7) the carbonate of lime is only 0·3 per cent. The concretions consist of a highly ferruginous and siliceous clay. So fine indeed are the particles of quartz in it that nearly all are siftable through muslin.

No. 10. No carbonate here. A rock somewhat like No. 5, but more sandy. The alkalies in No. 10 are potash 1·87, soda 1·36 per cent.; total 3·23, of which 0·56 was extractable by acid.

A composite of the 'insoluble in acid' of the above marls qualitatively examined showed there to be present in addition to much silica and some alumina the following oxides:—TiO_2, ZrO_2, Fe_2O_3, Cr_2O_3, traces CaO, MgO, K_2O, Na_2O. The persistence of zircons and chromite in sands is well attested. One of us some years ago noticed the occurrence of both these minerals in the sand of the London clay. The zircon was present to the extent of 0·4 and the chromite to 0·07 per cent. of the sand.

No. 13. Hay Mill, like the Woolhope specimen, is a highly siliceous limestone with about 40·7 per cent. of carbonate of lime as against 64·4 per cent in the Woolhope.

No. 16 is the analysis of the layer of fish remains from the Bone Bed, and No. 16*a* that of the immediately subjacent sandstone. No. 16 is obviously rich in phosphate and carbonate of lime, whilst No. 16*a* has no carbonate, though it has a little phosphate.

No. 17. There were casts of shells on one surface but no visible particles of shells. No. 17 is the analysis of the sandstone just below the shell casts. It shows 15·2 per cent. of carbonate, also a little phosphate. It is noteworthy that in this instance we should have carbonate in the subjacent layer of sandstone, whereas it did not occur in the sandstone just below the Bone Bed. It may be that bones of fish withstand in a greater degree the

solvent action of percolating water than do the shells of molluscs. The surface of No. 17 showing shell casts, but no shells, was rasped with a file. The raspings gave 6·0 per cent. of carbonate of lime, indicating the completeness of the leaching of the shell remains by water.

No. 18. Here the carbonate of lime is but sparingly represented. The rock is of similar composition to No. 10.

Nos. 19 and 20 have already been described.

GENERAL REMARKS.

The series of rocks to which these analyses refer are distinguished in mechanical structure by the fine texture of their component parts. This particular characteristic extends from the top of the Old Red Marl to the lowest exposure of the Upper Silurian. True, there are coarser sandstones interbedded, but the grit is not in any of our specimens noticeably coarse. The Old Red Marl though largely used for brick-making contains remarkably little real clay, consequently it readily crumbles when exposed to the weather. Doubtless this mechanical characteristic is favourable to the formation of soil, and the presence of diffused carbonate of lime, potash and, occasionally, phosphate of lime in a form readily to be assimilated will assist in accounting for the richness of the vegetation on this horizon. There are, it is true, evidences of glacial drift having been laid down in places, and probably this drift has been itself reassorted by water action. One of us found a typical Eskdale, Cumberland, granite pebble in the gravel pit near the racecourse, a striking evidence of a great drift from the north.

The main features of the soil are, however, due to local crumbling and disintegration, and the soil is largely "sedentary."

The Silurian limestone rocks analysed are remarkable for the quantity of sand-grains they contain, sometimes to such an extent as to suggest sandstones infiltrated by carbonate of lime; in other cases the carbonate of lime preponderates.* Phosphate of lime is often present in sufficient quantity in the limestone and mud stones to influence vegetation. The texture of the rocks, as already observed, is, as a rule, very fine. A study of the table of analyses will, we think, impress one with the conviction that the Silurian rocks in the neighbourhood of Ludlow are particularly well constituted for the formation of rich loamy soils by ordinary atmospheric and chemical decomposition, quite accounting for the luxuriance of the vegetation and general fertility of the Silurian areas.

That these Silurians were mostly laid down in very quiet seas is also proved by the fineness, as we have shown, of the grains composing them.

The Old Red Marl shows very little current action, but whether the beds deposited are fresh water or marine our analyses do not enable us to say.

The scenery, which is of an exceptionally lovely nature, is the outcome of original sedimentation, after-movement and great denudation.

The hard gritty limestone bands have greatly influenced the lines of folding upon which the denuding agencies have acted in the Silurian areas.

The intermediate mudstones yielding more readily to disintegration give prominence to the limestone bands. The enormous denudation the country has undergone

* Sir Roderick Murchison, in Siluria (page 128, fifth edition), refers to "the want of persistence over wide areas of any mass of solid limestone in the centre of the Ludlow formation." "Even where the lime is sparingly distributed, the rock is a highly calcareous flagstone, and may generally be recognised by its well-defined joints and predominant fossils."

Again (page 129), "The Aymestry limestone is a sub-crystalline earthy rock, arranged in beds from one to five feet thick, the lamina of deposit being marked by layers of shells and corals."

over a large area is clearly shown by the preservation of Carboniferous beds at Clee Hill by the injected basalt, at a height of over 1,200 feet above sea-level, constituting one of the most interesting geological escarpment features in England.

We trust that these investigations, though on a modest scale, may help in directing geologists' attention to the intimate relations between the chemical constitution of rocks, their external forms, the soils resulting therefrom and the vegetation they support.

Finally, we would wish to call attention to a paper by Miss Elles and Miss Slater, entitled, "The Highest Silurian Rocks of the Ludlow District" (Q.J.G.S., May, 1906, Vol. LXII.), an excellent detailed geological study of the area from whence our specimens were collected. It would appear that since Sir Roderick Murchison's time this locality has been somewhat neglected. Our study, though confined to the structure and chemical character of the rocks and their influence on the scenery, may, we trust, usefully supplement in this direction the systematic geological work of Miss Elles and Miss Slater.

PROCEEDINGS

OF THE

Liverpool Geological Society.

SESSION THE FORTY-NINTH.

ERRATUM.

Proceedings Liverpool Geological Society, Vol. X., Plate IX., for "Flaybrick Hill," read "Storeton."

PART 4. VOL. X.

LIVERPOOL:
C. TINLING AND CO., LTD., PRINTERS, VICTORIA STREET.

1908.

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ADDITIONS TO THE LIBRARY OF THE LIVERPOOL GEOLOGICAL SOCIETY, 1907-8.

The usual Proceedings and Transactions of the various Scientific Societies have been received for the Library of the Society during the past Session, also:—

British Association Report, 1907.—Leicester Meeting.

British Museum.—" A Guide to the Elephants, Recent and Fossil." 1908.

" Carboniferous of the Appalachian Basin," by Prof. J. J. Stevenson. Presented by the Author.

Geological Survey of the United Kingdom.—" Summary of Progress for 1906 and 1907."

" The History of the Geological Society of London," by Horace B. Woodward, F.R.S. Presented by the Society.

Geological Survey of Canada.—Annual Report, 1904. " The Falls of Niagara." Maps, etc.

Geological Survey of New Zealand.—Bulletins, 1907.

,, ,, Western Australia.—Bulletins, 1906.

,, ,, Victoria.—Report, 1907.

,, ,, Maryland.—Reports.

,, ,, United States :—

Annual Report, 1907.

Mineral Resources, 1906.

Atlas Folios.

Topographical Atlas Sheets.

Bulletins, &c.

Geological Commission of the Cape of Good Hope.—Reports, 1905-1906. Maps.

New York State Museum.—Reports.

Palæontographical Society.—Vol. lxi., 1907.

Report Royal Commission on Coast Erosion, 1907.

PROCEEDINGS

OF THE

LIVERPOOL GEOLOGICAL SOCIETY.

SESSION FORTY-NINTH.

OCTOBER 8TH, 1907.

THE PRESIDENT, DR. A. R. DWERRYHOUSE, in the Chair.

The Officers and Members of Council for the Session were duly elected.

THE HON. TREASURER gave his Annual Statement of Accounts, which was unanimously adopted.

Professor W. M. DAVIS, Harvard University, U.S.A., was elected an Honorary Member. Mr. C. B. TRAVIS, 9, Barton Road, Walton: proposed by T. MELLARD READE, C.E., and W. A. WHITEHEAD, B.Sc.; Dr. W. H. QUILLIAM, 21, Fairfield Crescent: proposed by J. LOMAS, F.G.S., and W. A. WHITEHEAD, B.Sc., were elected Ordinary Members.

EXHIBITS :—

Septarian nodule from Limestone of Derbyshire, by W. A. WHITEHEAD, B.Sc.

Vertebrate remains from Georgia, by W. SCHOFIELD.

THE PRESIDENT then read his Annual Address.

OCTOBER 14TH, 1907.

THE VICE-PRESIDENT, J. LOMAS, F.G.S., in the Chair.

Professor W. M. DAVIS, of Harvard, delivered a Lecture, entitled :—

"THE SCULPTURE OF MOUNTAINS BY GLACIERS."

The meeting was open to the public.

NOVEMBER 12TH, 1907.

THE VICE-PRESIDENT, J. LOMAS, F.G.S., in the Chair.

EXHIBITS :—

Specimens of rock salt, gypsum, anhydrite, dolomite, &c., from Salt Mountain, Biskra, Algeria (lent by Professor LISTER, Cambridge), by J. LOMAS, F.G.S.

Remains of Ichthyosaurus, and other fossils, from the Lias of Coventry, by S. E. GOULDSON.

The following Paper was read :—

"NOTE ON THE MINERALOGICAL CONSTITUTION OF STORETON SANDSTONE."

By J. LOMAS, F.G.S.

DECEMBER 10TH, 1907.

THE VICE-PRESIDENT, J. LOMAS, F.G.S., in the Chair.

EXHIBIT :—

Footprints from the Oolite (probably Deinosaur), by HAROLD BRODRICK, M.A.

The following Papers were read :—

"NOTE ON THE OCCURRENCE OF MARINE PEAT AT UNION DOCK, LIVERPOOL."

By J. LOMAS, F.G.S.

"THE POST-GLACIAL BEDS AT GREAT CROSBY AS DISCLOSED BY THE NEW OUTFALL SEWER."

By T. MELLARD READE, C.E., F.G.S.

JANUARY 14TH, 1908.

THE VICE-PRESIDENT, J. LOMAS, F.G.S., in the Chair.

Mr. H. C. ASKEW, 88, Selborne Street: proposed by J. LOMAS, F.G.S., and W. A. WHITEHEAD, B.Sc., was elected an Ordinary Member. Mr. H. T. WHITE, 14, Princess Terrace, Oxton: proposed by W. MAWBY and W. A. WHITEHEAD, B.Sc., was elected an Associate Member.

EXHIBITS :—

Keuper Marl with markings, by C. B. TRAVIS.

Flint Implements; Smooth Rubbing Stones from submerged forest, Leasowe, by Dr. W. H. QUILLIAM.

Wind-etched Stone from New Zealand, and Photographs of the Arizona Desert, by J. LOMAS, F.G.S.

The following Paper was read :—

"NOTES ON SOME MARKINGS OTHER THAN FOOTPRINTS IN THE KEUPER SANDSTONES AND MARLS"

(With Lantern Illustrations.)

By H. C. BEASLEY.

FEBRUARY 11TH, 1908.

THE PRESIDENT, DR. A. R. DWERRYHOUSE, in the Chair.

EXHIBIT :—

Large Pebbles from the Bunter in the neighbourhood of Stoneycroft, by HENRY CAPPER.

The following Paper was read :—

"EVOLUTION OF SOME BRITISH RIVERS"

(With Lantern Illustrations.)

By Rev. W. LOWER CARTER, M.A., F.G.S.

MARCH 10TH, 1908.

THE VICE-PRESIDENT, J. LOMAS, F.G.S., in the Chair.

EXHIBITS :—

Photographs of Impressions of Triassic Plants, by H. C. BEASLEY.

Contour Models of the Mersey Basin, showing respectively Rainfall and Geology, by J. LOMAS, F.G.S.

The following Paper was read :—

"NOTES ON THE GEOLOGY OF THE COUNTRY ROUND GARSTANG."

By E. DICKSON, F.G.S.

APRIL 14TH, 1908.

THE VICE-PRESIDENT, J. LOMAS, F.G.S., in the Chair.

EXHIBITS :—

Pre-historic Remains, including an Antler and Perforated Stone from Dock Excavations, Birkenhead (lent by Mr. LYSTER), by J. LOMAS, F.G.S.

The following Paper was read :—

"ANALYSES OF LONGMYNDIAN ROCKS."

By T. MELLARD READE, F.G.S., F.R.I.B.A., and PHILIP HOLLAND, F.I.C.

Field Meetings :—

1907.

April 27th—West Kirby (Joint Excursion with the Nature Study Club).

Leader—J. Lomas, F.G.S.

May 25th—Ashurst Beacon.

Leader—W. D. Brown.

June 15th—Rivington.

Leader—J. Lomas, F.G.S.

Aug. 24th—Llangollen.

Leader—J. Lomas, F.G.S.

Dec. 21st—Leasowe.

Leader—J. Lomas, F.G.S.

1907.

Apr. 16th to Apr. 20th—The Berwyns (Joint Excursion with Yorkshire Geological Society).

Leader—J. Lomas, F.G.S.

THE LIVERPOOL GEOLOGICAL SOCIETY, in Account with W. H. ROCK, Hon. Treasurer.

Dr. SESSION 1906-1907. **Cr.**

Dr.	£	s.	d.
To Rent, October, 1906, to October, 1907..	5	0	0
,, Tinling & Co.—Printing and Stationery	6	7	3
,, ,, Printing Proceedings...	9	13	9
,, Mrs. Ellick—Teas, Attendance, &c. ...	6	14	8
,, Secretary's and Librarian's Expenses, &c.	3	3	4
,, Geological Magazine Subscription ...	0	18	0
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,, Binding Books	2	18	6
	£35	16	6
,, Balance carried down	36	5	9
	£72	2	3

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1905-6—Arrears	£6	11	0			
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1 Life Member..	10	10	0			
1907-8—In Advance......	2	12	6			
				61	10	6
				£72	2	3
By Balance brought down				£36	5	9

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(Signed), GEO. H. ASHWORTH, HENRY CAPPER, } AUDITORS.

(Signed), W. H. ROCK, HON. TREASURER.

LIVERPOOL, *8th October, 1907.*

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READE, A. L., Park Corner, Blundellsands.

WHITE, H. T., 14, Princess Terrace, Oxton.

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* Have read Papers before the Society. † Contribute to Printing Fund.

PRESIDENTIAL ADDRESS TO THE LIVERPOOL GEOLOGICAL SOCIETY.

8TH OCTOBER, 1907.

ARTHUR R. DWERRYHOUSE, D.SC., F.G.S.

In reviewing the work of the Society during the last session it is pleasant to find that, although there is a slight diminution in the number of members on our roll, the energy with which the Society pursues its work shows no falling off.

During the year we have had the misfortune to lose by death one of our oldest members, Michael Fitzpatrick, who, though he has not been a regular attendant at our meetings of late years, was well known to many now present.

Four members have resigned during the year and two new ones been elected, making the total of our ordinary and associate members at the present time fifty-four.

It is convenient and profitable on an occasion such as this to review the most important discoveries and events of the year, and at the same time to take stock, so to speak, of the position of scientific inquiry in so far as it affects our own province.

It is my intention to deal not so much with discoveries of a purely geological character as with recent advances in other branches of science which have, or may have in the immediate future, a profound influence upon geological thought, and upon the progress of geology.

There is, however, one great event of the present year which stands out, and will ever stand out, as a landmark in the history of Geology—the Centenary celebration of the Geological Society of London—the pioneer of our science. Never, I suppose, have so many geologists of

note been gathered together under one roof as assembled on the 26th of September last, to hear the address of Sir Archibald Geikie in the house of the Institute of Civil Engineers.

The president dealt with the condition of geological thought at the time of the Society's foundation, and the contrast between the methods of that time and of to-day, as brought out in the course of the address, were of the utmost interest.

To those present the chief charm of the gathering was in meeting on friendly terms so many distinguished geologists, who until that time had, at all events to the younger men, been merely revered names.

English geologists may well feel proud of the high esteem for their Society and its great work expressed so spontaneously and with such evident sincerity and enthusiasm, by the representatives of the many institutions and societies present at the celebration.

Our own Society was represented officially by Mr. Lomas, who presented the following address on our behalf.

To the President, Council, and Fellows of the Geological Society of London.

The members of the Liverpool Geological Society desire to convey their warmest congratulations to your Society on the occasion of the hundredth anniversary of your foundation.

As a daughter Society, which hopes to celebrate its own Jubilee in 1909, we approach the great Mother Society with sincere gratitude for the kindly guidance and encouragement which it has at all times so willingly given.

We recall with pride that four of our past Presidents have received recognition from your Council in the form of Medals and Grants of Funds. The

bestowal of these honours has acted as a stimulus, not only to the recipients, but to all our members.

We feel it would be impossible to over-estimate the great part which your Society has played in the marvellous developments which have taken place in geological thought during the past hundred years.

Your Society has ever extended a guiding hand to all who have earnestly laboured to discover and record geological truths both at home and abroad.

It is our most earnest wish that the distinguished past may be precursor of a long, happy, and even more useful future.

(Signed) ARTHUR R. DWERRYHOUSE, President.
W. A. WHITEHEAD, Hon. Secretary.

The Royal Institution,
Liverpool.

The History of the Geological Society of London, by Horace B. Woodward, recently published by the Society, contains an admirable account of the infancy and growth, not only of the Society, but to some extent also of many of the geological theories now currently accepted.

We cannot but feel gratified to find that so many past and present members of our own Society are singled out from the distinguished company of the Fellows of the Geological Society for special mention in this volume.

Thus we find the names of Callaway, Morton, and Reade cited in connection with their various publications, while no less than five of our ordinary members have received awards of medals and funds.

We find, on reference to the history, that the Geological Society was founded with the object of collecting information concerning the rocks at first hand, and would have no dealings with the idle speculations

which in those days were fashionable, "leaving to others the explanation and origin of all things terrestrial and celestial" by means of the then popular theories of the earth.

An interesting account of the early views on cosmogony may be found in Geikie's "Founders of Geology," and it is not my present purpose to enter into details of these. In the 17th and 18th centuries the principal if not the sole qualification deemed necessary for one who would pose as a leader in cosmogony was the possession of a vivid and almost unbounded imagination, and the founders of the Society acted wisely in leaving all such matters alone.

Surprising as has been the growth of geological science, other branches of knowledge have advanced with equal rapidity, and the application of facts and methods discovered in its various departments has at length—a century later—placed us in the position in which it is possible with some hope of success to inquire into the origin of the earth.

The subject has in fact passed from the realm of speculation into that of legitimate hypothesis.

It may be said that such investigations belong more properly to the domain of astronomy than to that of geology, but so many of our theories regarding the interior of the earth and the source of mountain-building forces are based upon one of the modern cosmogonies, namely the nebular hypothesis of Laplace, or upon some modification of it, that it is most necessary for us to inquire into the probability of this explanation.

There are at present three leading hypotheses with regard to the formation and evolution of the solar system.

(*a*) The nebular hypothesis of Laplace.

(*b*) The meteoritic hypothesis of Lockyer and Darwin.

(*c*) The planetesimal hypothesis of Chamberlin.

Of these the first two fall under the same head from a geological point of view, inasmuch as they both derive the earth from a highly-heated mass of gaseous or quasi-gaseous matter which has undergone a gradual shrinkage through loss of heat into space.

The third and newest hypothesis, however, does not involve a highly-heated gaseous condition, and indeed, taken in conjunction with recent discoveries in physics and chemistry, may eventually lead us to the view that our earth has never been hotter than it is at present.

Contraction through loss of heat has long been considered inadequate for the production of mountain folds even on the Laplacian view, and if some form of the planetesimal hypothesis is to be adopted we shall have to profoundly alter our views, both as regards the ultimate causes of mountain building, and the physical and chemical constitution of the earth's interior.

It is therefore of the utmost importance that we as geologists should become acquainted with these newer views so that we may learn on which side the balance of evidence lies.

I propose, therefore, briefly to review the objections which have been raised to the older theories and the attempts which have been recently made by a distinguished geologist—Professor T. C. Chamberlin—to construct an hypothesis which shall better explain the present condition of the solar system.

Objections to the Laplacian View.

From time to time astronomers and physicists have called attention to various difficulties in the way of accepting the nebular hypothesis of Laplace in its entirety.

At the time of its promulgation the hypothesis explained practically all the known facts relating to the

solar system, and the probabilities in favour of its correctness were very great indeed.

Since the time of Laplace, however, so many new and significant facts have been added to our knowledge, and so many new methods of research discovered, that the time is now ripe for a reconsideration of the whole matter.

Most important amongst the discoveries since Laplace's time are the true nature of Saturn's rings by means of the spectroscope, the fact that certain satellites move round their primaries in less time than that occupied by a rotation of the primary, and that some of these bodies have retrograde motion.

Further, the formation of rings from a rotating gaseous spheroid by a process of contraction under the influence of gravitation, seems to be extremely problematical, and it is not clear by what system of dynamical changes such rings, if formed, could condense into planets and satellites.

It is, of course, certain that the centrifugal acceleration due to rotation would gradually increase during the contraction of a rotating spheroid, and that it might eventually equal the centripetal acceleration due to gravity, also that when this happened the part of the spheroid so conditioned would cease to contract.

These conditions would, of course, first be reached at the equator of the spheroid, but there seems to be no dynamical reason why the matter left behind owing to the further contraction of the nucleus should assume the form of a ring.

On the contrary, it seems almost certain that the gas would acquire the requisite centrifugal acceleration molecule by molecule, and would be left behind in the form of a continuous sheet on the plane of the equator.

The most serious objection to the nebular hypothesis which has been raised, is that urged by Moulton and

Chamberlin, and connected with the relative distribution of mass and momentum in the solar system.

Moulton has shown "that if the solar system were converted into a gaseous spheroid, so expanded as to fill Neptune's orbit, and so distributed in density as to conform to the recognised laws of gases, and if the whole moment of momentum now possessed by the solar system be given to it, it will not have a rate of rotation sufficient to detach matter from its equator, and would not acquire such a rate until it had contracted well within the orbit of the innermost planet."

Moulton's computations further appear to show that taking the present moment of momentum of the solar system as unity, its value at the time of the birth of the various planetary rings must have been somewhat as follows:—

Neptune	200
Jupiter	140
Earth	1800
Mercury	1100 etc.

Now it is a fundamental law of mechanics that the moment of momentum of any freely rotating or revolving system remains constant if not influenced from without, whatever internal changes the system may undergo.

Thus appears a very great discrepancy, and one that varies irregularly from stage to stage.

Again on Moulton's calculations it would appear that Jupiter and his satellites, containing not more than one-thousandth part of the whole mass, carried off 95 per cent. of the total moment of momentum when it separated from the main mass.

There are many other objections to the Laplacian view which are very difficult to explain away, e.g.:— The inner satellite of Mercury, Phobos, completes its circuit of the planet in rather less than one-third of the

Mercurian day, whereas after the separation of the Phobos ring, Mercury, through further contraction, should have acquired a higher angular velocity. The small bodies forming the inner edge of Saturn's rings also revolve in about half the time of the planet's rotation.

The transference of energy from the planet to the satellite as a result of tidal retardation appears by computation to be utterly inadequate to account for these irregularities.

The Meteoritic Hypothesis.

This hypothesis, of which there are several forms, appears likewise to be open to many grave objections.

In the form given to it by Darwin a swarm of meteorites already aggregated from a primitive dispersion in space, is made to behave dynamically as though it were a gas.

The planets were formed by the detachment of matter from the equatorial region of a rotating spheroid, resulting from the evolution of this swarm, and whether we look upon this spheroid as gaseous or quasi-gaseous, the theory seems to be open to nearly all the objections urged against the nebular hypothesis.

The Planetesimal Hypothesis.

According to this, the latest of the three hypotheses, the parent nebula of the solar system was made up of innumerable small bodies, planetesimals, revolving about a central gaseous mass much as do the planets to-day.

In the evolution of such a nebula as the one postulated, there is no radical change in the system of dynamics such as that supposed to have taken place in the case of the meteoritic theory, namely, from collisional relations to orbital, and it also appears to satisfactorily explain the irregular distribution not only of the planets themselves but of mass and momentum throughout the system.

Professor Chamberlin favours the view that this nebula was of the spiral type, which is by far the most common in the heavens.

Of the very large number of nebulæ which falls within the power of the Crossley reflector, an overwhelming proportion belongs to the spiral type.

Furthermore, the spectra of these spiral nebulæ, being of the continuous type, indicate that the matter of which they are constituted is for the most part solid or liquid, and since the latter condition is confined to a comparatively small range of temperature, we may conclude that the solid state predominates.

Furthermore, the mode of origin of the nebula, ascribed by Chamberlin to the tidal disruption of an ancestral sun, caused by the near approach of a body of somewhat similar dimensions, is capable of explaining not only the spiral form of such nebula, but also the exceedingly complex structure and coarse grain of the meteorites which sometimes fall upon the surface of the earth, and which, according to the hypothesis, are to be looked upon as belated planetesimals only now being gathered in by the earth.

In a case of tidal disruption of a rotating body matter would be projected from its surface in two arms, having their points of origin diametrically opposite to each other; the matter would in all probability be unequally distributed in these arms, and thus there would be "knots" where the fragments were more closely congregated, as has been observed to be the case in all spiral nebulæ observed up to the present time.

The outward movement combined with the movement due to the rotation of the original body would suffice to give the spiral form, and it is held that when the outward force was eventually counteracted by gravitation, the fragments would naturally fall into elliptical orbits about the common centre of gravity of the system.

The knots in the arms are believed to have formed the nuclei of the planets, and the principal mode of accretion to have been by the crossing of the elliptical orbits of the planetesimals due to the revolution of their lines of apsides.

This hypothesis appears to meet most of the difficulties raised against the Laplacian view, indeed Chamberlin claims that it removes them all. In his own words: "The planetesimal hypothesis postulates a simple mode of origin of the nebula connected with the not improbable event of a close approach of the ancestral sun to another large body."

"It assigns the gathering in of the planetesimals to the crossing of the elliptical orbits in the course of their inevitable shiftings. Out of this process and its antecedents it develops consistent views of the requisite distribution of mass and momentum, of the spacing out of the planets, of their directions of rotation, of their variations of mass, of their varying densities, and of other peculiarities."

"It deduces a relatively slow growth of the earth, with a rising internal temperature developed in the central parts and creeping outwards."

Chamberlin further points out that "with such a mode of growth the stages of the earth's early history necessarily depart widely from those postulated by the Laplacian and meteoritic hypotheses," and proceeds to sketch the progress of events which lead up to "the beginning of the legible record of Archæan times." It is here that the matter becomes of such deep geological interest.

The nebular hypothesis of Laplace requires that the earth should be a cooling body, first gaseous, and then passing through successive stages of liquid and solid; while if we accept the planetesimal hypothesis of

Chamberlin it is necessary to assume that the matter which by accretion formed the earth was originally cold, and that the temperature has gradually risen during contraction by the conversion of gravitational energy into heat.

Obviously the events assumed to precede the formation of the earliest fossiliferous rocks will be very different under the two views.

Under the Laplacian view it seems necessary to assume that the earth passed through a period during which it was a fluid globe with a vaporous envelope, far exceeding in dimensions and density the present atmosphere. After this there must have succeeded a period of at least partial solidity (as regards the crust), but in which the temperature was still too high to allow of the condensation of water, and finally a prolonged period during which the waters slowly cooled, and the rocks of the primitive crust became more or less weathered by the absorption of carbonic acid from the air, until finally the surface was fit for vegetation and for animal life.

To this view geologists have raised from time to time many objections.

It would seem probable that in the event of a cooling liquid globe the first formed crust would be homogeneous, and would probably take the form of an exceedingly coarse-grained holocrystalline rock, which one would expect to find forming a universal substratum.

It may be argued that this original crust has been hidden by subsequent accumulations of pyroclastic matter, but since the great agent of volcanic activity—water—was, according to the theory, still in a state of vapour in the atmosphere, it becomes difficult to find the source of the explosive energy necessary for their formation.

We have been in the habit of appealing to the great masses of granitoid gneiss in the N.W. Highlands, in Canada, and elsewhere, as the remains of this primæval crust, but we now know that many of these granitoid masses are intrusive, and although this does not require that all of them should be so, it raises a strong presumption that we must look elsewhere for portions of the first crust.

"If the trend of further investigation should follow the present tendency, and exclude the accessible rocks of the Archæan Series from the original crust, the molten theory in its original form will have lost its observational support."

The theory also seems to demand that the molten globe should be devoid of gaseous material such as now constitutes the atmosphere and hydrosphere.

The primitive atmosphere should therefore have contained all the water and the CO_2 now bound up in limestones and other carbonaceous material.

Under these circumstances it seems difficult to account for extensive volcanic action since the tendency in a cooling body would surely be towards absorption, and not towards the explosive expulsion of gaseous matter.

Early life does not seem to point to the existence of any such dense carbonic acid-laden atmosphere as the theory requires, and the physical condition of the earth during early palæozoic times lends no more support to the existence of this massive and dense atmosphere than do the fossils.

Let us now consider the probable stages of evolution on the supposition that the earth may have been formed by the gathering together of small cold solid bodies, as for example the planetesimals of Chamberlin.

The original nucleus or knot must have consisted of heavy molecules, as lighter ones would have escaped the gravitational control of so small a body.

Thus we must be prepared to recognise the possibility of an atmosphereless stage.

When the growing earth reached a sufficient size it would be able to capture and retain not only solid bodies but also gaseous molecules, and thus our atmosphere, probably in part, originated. The planetesimals, however, like the meteorites of to-day, probably contained considerable quantities of occluded gas.

(Meteorites carry, on the average, several times their volumes of condensed gas.)

This occluded gas might form part of the atmosphere by extrusion at a later stage.

The Birth of Volcanic Activity.

Under the above view the earth would consist mainly of solid matter, but would also contain large quantities of occluded gas, and the question now arises whether the heat developed by compression as the earth increased in size would be sufficient to raise the mass to such a temperature as to expel these occluded gases.

It is probable that the heat generated by the infall of the planetesimals at the surface of the growing earth would be lost by radiation, almost, if not quite, as fast as it was produced, and therefore no great rise of temperature can be assigned to this cause.

The other sources of internal heat are quasi-gaseous condensation of the nucleus, which, however, was probably of little moment, and heat from central compression.

This last appears to be by far the most important source of heat in the growing globe.

A computation of this condensational heat gives a result ample to meet all the requirements of the case.

There is still another source of heat which, in view of recent discoveries in the domain of physical chemistry,

is of particular interest, namely by molecular rearrangement, and even, as we now believe, atomic rearrangement.

The molecular arrangements of bodies forming the planetesimals must have been such as were stable under extremely low pressures.

Under the pressures developed in the growing earth, it seems inevitable that these molecules would undergo a change in the direction of greater complexity, with a lowering of specific heat and consequent rise in temperature.

We now know that in addition to all the above causes, there are interatomic forces capable of producing heat, such, for example, as those which come into play in the case of the various radio-active bodies.

It therefore seems possible that a planet formed by the gathering in of cold planetesimals could during its growth reach temperatures such as are necessary for volcanic activity.

The manner in which volcanic centres would arise would, of course, be very different from the accepted views, in which they are looked upon as the residue of a once molten globe, or as portions of a solid but potentially liquid globe rendered fluid by release of pressure.

The temperature of the earth being mainly due to compression would, of course, be highest at the centre but heat would be constantly flowing outwards into regions where pressures and consequently melting points were lower.

The material of the interior was, according to the theory, mixed plantesimals, together with considerable quantities of gas which they carried in with them.

In this mixed mass it is assumed that there was a considerable range of melting points, and that in consequence local *spots* of fusion were produced.

It is then thought that these more fluid portions rose

towards the surface increased in volume and joined others. As they rose to higher and higher levels they would carry an excess of heat over and above that necessary to maintain their state of fusion, and would consequently be able to melt their way towards the surface.

It seems probable that many, if not all, of these tongues of molten material would in the early stages stop short at the horizon where the temperature was below the surface melting point, except where they carried a large excess of heat.

In outer layers the young earth consisted of newly-fallen planetesimals, and was therefore in a more or less fragmentary state with an open texture, and as soon as the tongues of molten material reached this zone they would be able to rise further by the displacement of the loose material.

In this region then, the lava tongues would probably give rise to various intrusions as batholiths, laccolites, etc., and in some instances the expansion of the contained gases would form at the surface explosion pits or craters which would be proportionately large owing to the low gravitational effect of the young earth, and the smallness or absence of atmospheric pressure.

The Origin of the Oceans.

Under the accretion hypothesis the oceans would commence to be formed when the water vapour in the atmosphere reached saturation point.

The fragmental zone already referred to probably contained a large quantity of water which had condensed within it before the atmosphere reached the state of saturation.

Mr. Chamberlin supposes that the first appearance of water at the surface was in the explosion pits, and that the positions of our great ocean basins were determined

even at this early stage by the relative frequency of these pits in different parts of the surface.

The whole of these opinions are so new and so different from all our time-honoured views, that it seems hardly profitable at the moment to follow their author into the various intricacies of mountain building, and the like.

It is well, however, to have these views before us, and should they be verified, as I think is most probable, by future work and computation, to see to it that our purely geological theories are in accord with the then accepted theory of the evolution of the solar system.

Thus if it were to be shown, with a considerable degree of probability, that the earth is not a cooling body, theories of mountain-building and earth movement generally, founded on contraction during cooling, would obviously have to be given up.

Nor is it in this branch only that the question affects geologists, and it therefore behoves them to keep a keen outlook for further advances in our knowledge of this and cognate branches of science.

Closely allied with the question of the evolution of the solar system is that of the duration of geological time.

Almost all the estimates of the age of the earth have been founded upon the supposition that the earth has been cooling steadily throughout the whole period represented by the sedimentary rocks, and that the temperature gradient in the earth's interior is due to the distribution of heat in a cooling body.

With the view that the earth is not necessarily a cooling body, and the discovery of the fact that quite considerable quantities of heat are being constantly liberated by such bodies as uranium and radium, the necessity for the imposition of comparatively narrow limits for geological time disappears.

Physicists now seem to be prepared to accede to even the wildest demands for more time, and to say that the temperature gradient is, in view of recent discoveries, no guide whatever to the duration of life on the globe. Thus at the British Association meeting at York the Hon. R. J. Strutt gave the results of the examination of a number of rocks, both igneous and sedimentary, and was led to the conclusion that there was very much more radium in all of them than would be needed to maintain the earth's internal heat if the earth were constituted of such rock throughout.

A rocky crust, 45 miles deep, would contain sufficient radium to maintain the earth's temperature gradient.

Mr. Strutt calculates that the temperature at the bottom of this crust, 45 miles thick, is about 1500°C., and states that "the inside nucleus, heated by the crust of radium-containing material, must be at this uniform temperature throughout, just as a loaf of bread which has been in an oven long enough takes up a steady temperature equal to that of the walls of the oven."

Thus he takes no account of any possible heat in the nucleus such as may have arisen from compression and the other causes.

The view that no part of the interior of the earth has a temperature of more than 1500°C. would, no doubt, greatly simplify our ideas as to its physical condition, but inasmuch as temperatures closely approaching to this are believed to occur in certain lavas actually extruded at the surface, Mr. Strutt's statement of the case must be received with great caution.

His opinion is based on the fact that the specimens of rock examined by him were found "to contain far more radium than would be needed to maintain the earth's temperature gradient if the earth were constituted of such rock throughout," and that therefore "the interior of

the globe does not contain radium, and that in all probability its composition is quite different in other respects also from that of the surface materials."

Geologists have frequently been accused of building great theories on insufficient foundation, but in this case I think they will wish to wait until more is known about radium and radio-activity generally before they assign the interior heat of the earth to that cause alone.

The whole question of radio-activity is still in its infancy, and there is room for much difference of opinion upon many of its phases, but it is a subject full of interest to the geologist, and one the development of which he cannot afford to ignore.

In still another way has the study of physical chemistry along modern lines brought forth a principle of the utmost importance to the study of geology.

The laws governing the distribution of bodies in solution, and the separation of solid bodies from solution, have of late received much attention, and it has been shown that this separation, on the cooling of a saturated solution of mixed bodies, is by no means so simple a matter as was once supposed.

It has, of course, been long known that the solubility of a solid in a liquid is largely affected by changes of temperature, and that different substances are affected in divers degrees. It is also known that the presence of one substance in solution reacts upon the solubility of another.

The law affecting the quantities of the various substances present at any time in a mixed solution has been found to follow a definite principle.

The phase rule has been successfully applied to the elucidation of such deposits as those of Stassfurth by Van 't Hoff and others, and recently attempts have been made to apply the principle to the separation of crystals from igneous magmas.

In the case of the cooling of simple solutions such, e.g., as brine, the rule can readily be applied and the quantities of water, ionised salt and solid salt, present at any temperature, can be shown by means of a curve.

When, however, a third substance is introduced the matter becomes much more complicated, and in the case of igneous rocks, where the number of substances is very large, it is at present impossible to apply the phase rule.

The bearing which the phase rule has had on petrology is this:—It has enabled us to learn and to state clearly and graphically very many facts hitherto unsuspected with regard to the simpler solutions, and has given us principles on which to build our theories with regard to the more complex case of magmas.

The eutectic mixture, though known to exist before the enunciation of the phase rule, receives much clearness from its application.

We are familiar with eutectic mixtures in steel and in some alloys, and we are now quite accustomed to look upon the so-called micro-pegmatitic structures of igneous rocks as produced by the solidification of eutectic mixtures.

By experimental work it has been determined that where two substances which are capable of forming such a eutectic are melted together and then cooled, if either of them be present in a proportion greater than that necessary to form the eutectic, it will separate out in the solid form until the eutectic point is reached.

In the case of many igneous rocks, such for example as the augite granophyres, the magma as a whole was evidently more basic than the eutectic of quartz and orthoclase, with the result that the excess of basic matter separated as pyroxene until the molten liquor had the composition of the quartz-felspar eutectic, which at a lower temperature solidified as a micropegmatitic intergrowth of those minerals.

Because this, the first eutectic found in igneous rocks, possesses a marked structure readily identifiable under the microscope, we must not conclude that all such eutectics will possess such structures.

We know that other minerals, such as augite and felspar, sometimes form a micropegmatitic intergrowth, and we are thus led to suppose that here also a eutectic has played its part.

There are many instances known in which by the separation of basic minerals a more acid eutectic has been reached, and I have lately been studying a case in which the reverse has taken place, viz., a magma of which the composition was more acid than the eutectic has thrown off, so to speak, its excess of acid matter in the form of quartz.

The granite mass of Eskdale in Cumberland is surrounded by a band of almost pure quartz in a fine-grained mosaic, which gradually shades inwards to the normal granite which, however, is a particularly acid one.

The mosaic-like rock on the margin contains 96·16% of silica, and the granite towards the interior of the mass a very much smaller proportion.

So far as is known in all laboratory experiments the eutectic is the last portion of the fluid to solidify, but if micropegmatitic structure is to be taken as pointing to a solidified eutectic, this does not always appear to be the case in igneous rocks.

In some rocks distinct phenocrysts of micropegmatite occur in a matrix which does not exhibit that structure, and these seem to demand some further explanation.

Though we are still much in the dark with regard to these matters, I am convinced that it is only by patient research along the lines laid down by physical chemistry that we shall reach any further elucidation of the many obscurities connected with such topics as the

differentiation of magmas and the order of crystallisation of the minerals in igneous rocks.

We must not lose sight of the fact that though experimental work in this direction is difficult, it is not impossible, and we may well take to heart in this connection the words of Petrus Severinus written in 1571: "Lastly purchase coals, build furnaces, watch and experiment without wearying."

SOME COMPARISONS

IN THE

WEATHERING OF BASALT.

By Thomas H. Cope, F.G.S.

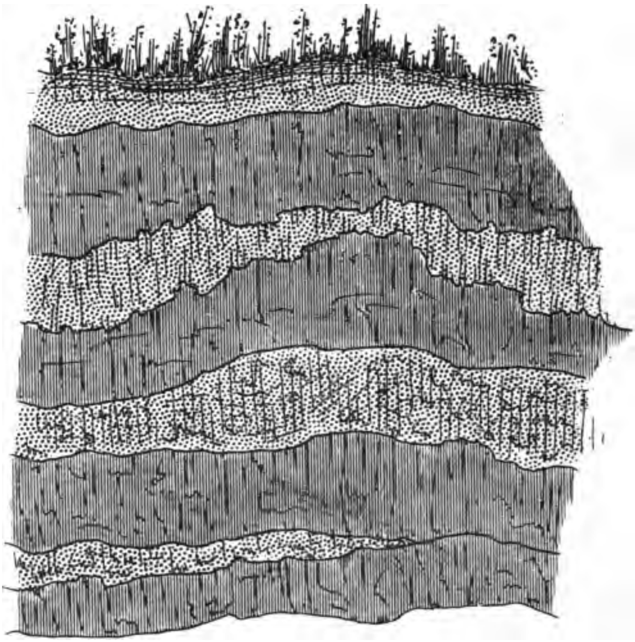
As all rocks break down under climatic agencies, Basalt, one of the least yielding of its group, is no exception to this universal law. Yet one may traverse for days the Islands of the Western Hebrides and meet with nothing so tedious as the limitless, great bedded tracts of the black Tertiary basaltic plateaux. Exceptions in texture and structure however occur, and it is with this in mind that I desire to draw attention to some curious sections, which might be placed on record with advantage. The time at our disposal will, nevertheless, yield little opportunity for elaboration. All the sections are taken from the island of Mull. It will be perhaps better to briefly describe these sections and to draw such conclusions later as seem most fitted to prove explanatory.

Section I. (Plate V.)

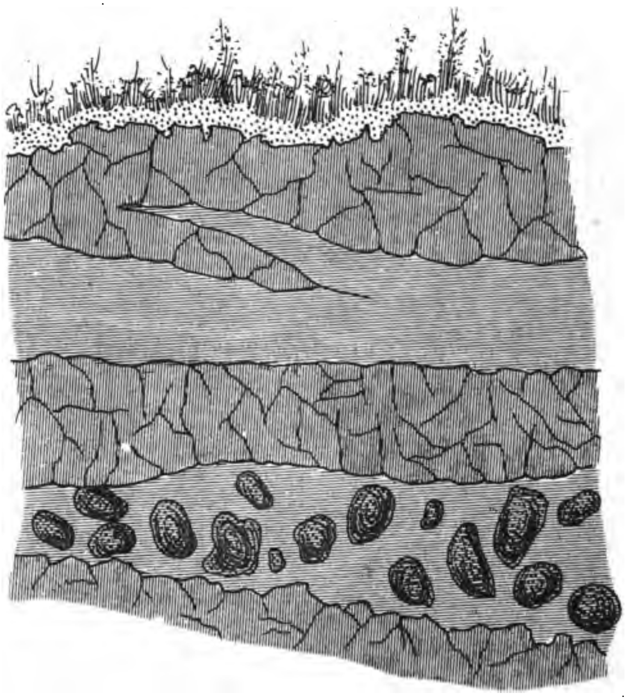
Is taken near the channel of Tobermory River. The section shows thin sheets of normal hard basalt with similar thicknesses of coherent brown sand intervening, the average of each being about 12 inches.

Section II. (Plate VI.)

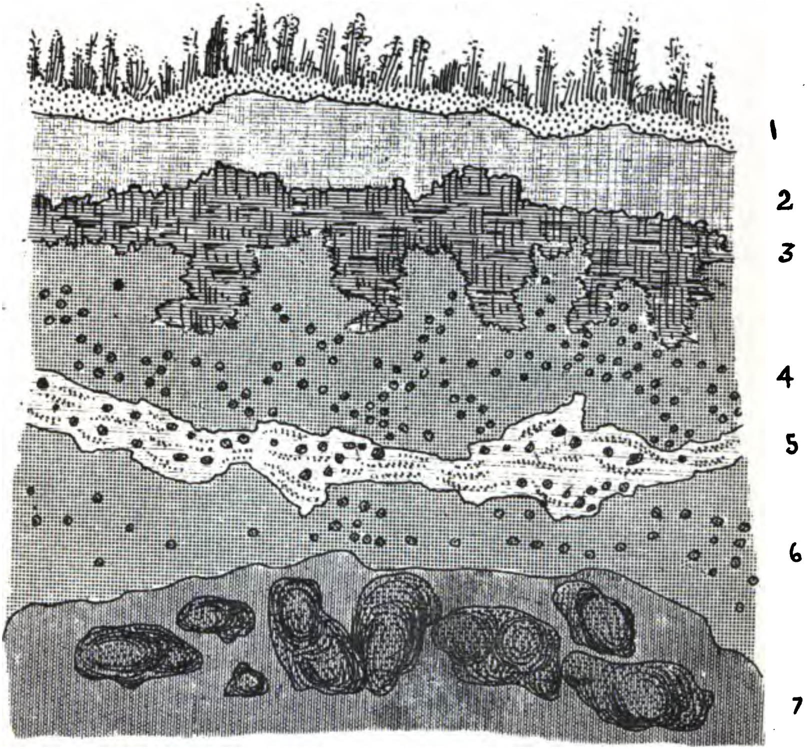
North of Dervaig is seen a section, where hard basalt beds, each some three feet thick, are intercalated with beds of sandy clay, which in one example passes upwards, as a tongue, into the highest rock-bed, even as this



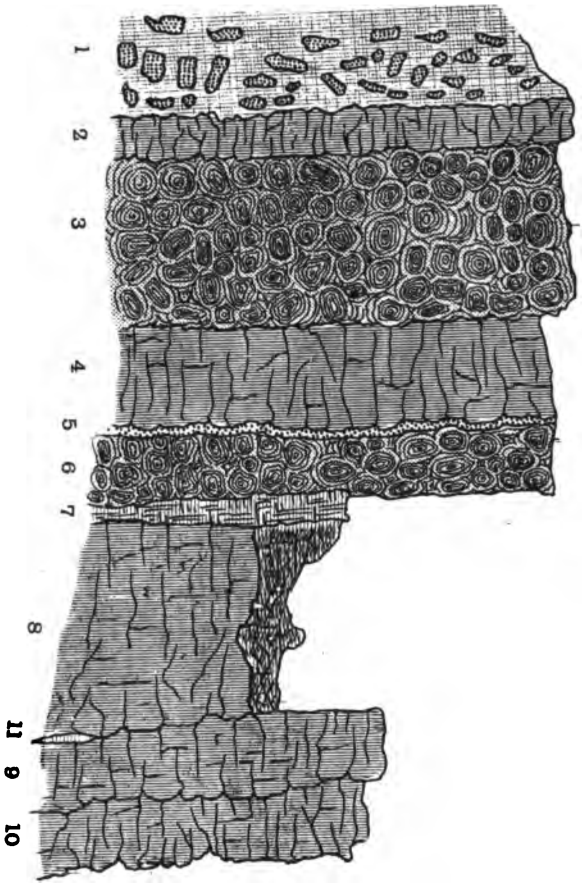
SECTION I.—TOBERMORY RIVER.



SECTION II.—N. OF DERVAIG, MULL.



SECTION III.—Near AROS HOUSE, TOBERMORY.



SECTION IV.—SAHLEN, MULL.

basaltic sheet protrudes a tongue downwards into the clay. Upper and lower surfaces of the hard rock are unweathered, intact, and show no signs of alteration.

Lower in the cliff are large masses of exfoliating basalt.

Section III. (Plate VII.)

This section was sketched near Aros House, Tobermory, and is worthy of attention. The sequence of beds downwards is as follows:—

1. Heather and peaty soil.
2. A few feet of red loamy earth.
3. Four feet of rough fissile basalt.
4. Many feet of yellow sand containing nests and regular lines of limonite "balls."
5. A thin decomposing sheet of basalt, stained by FeO, and with defined lines of masses and crystals of angular quartz.
6. Yellow sand again, with limonite spheroids and round fragments of basalt with zeolites (analcite natrolite and newlandite).
7. Formerly hard basalt, now shows only exfoliating masses, of large size, which are automatically released from the sheet by disintegration cavities forming round those masses apparently selected for cuboidal weathering. The bed in which these masses lie is a yellow ochreous clay.

Section IV. (Plate VIII.)

A section near Salen discredits the belief that the plateaux sheets are universally horizontal in habit. In the field there certainly exists a certain parallelism of beds, as one might expect from gentle fissure eruptions.

But in Tertiary times, or even later, dislocation, upheaval, faulting and folding are not entirely improbable phenomena. This is a case, possibly, where basalt sheets, apparently horizontal, are seen to be inverted when weathering attacks the lines of least resistance. The section clearly proves some disturbance of the level plateaux which can only be seen after a long period of atmospheric alterations. These sheets, in former descending order, are now changed from the horizontal to the vertical position. The sequence, therefore, reading from left to right, is as follows:—

1. Loose sandy soil with basalt fragments and some decaying vegetation.

2. 4. 9. 10. Are hard black basalts showing an inclination to weather red. Horizontal jointing (as "master" cracks) are filled with sand and calcite.

3. 6. Are nodular basalts, much altered with cuboidal exfoliation.

5. A vein of nearly pure steatite.

7. Hard gray basalt jointed rhombohedrally in two directions.

8. Quarryman's débris covering country rock.

11. A quartz "geode," 14 inches long, accentuates the divisional plane of bedding.

Conclusions.

These four sections average 30 feet in height, generally face the prevailing winds from the Atlantic, and certainly its storms. In sections 1 and 3 a backing of solid rock has been proved in the sand and clay beds, by boring, the soft portion being a mere facing of decomposition material. Thus, here, there is no possible

proposition of the existence of former terrestrial land surfaces between successive lava flows, and there are some points in favour of this theory.

1. The superficial nature of this weathering (say 6 inches deep).

2. The absence in sections 1, 2 and 3 of any organic matter, the clay and sands being limited to entirely inorganic compounds with no humic acid present.

3. Oceanic weathering may exert a greater potential force on the decomposition of certain basic rocks than atmospheric agency of land climatic forces can produce, suggests in some measure the drastic character of its attack.

4. The remaining hard basalt sheets possess sharp, unweathered demarcation lines, *not* as if passing upwards insensibly into soil. Further in the sand beds there is a clear trace of fissile structure.

5. Further there is found in all these sandy and interleaved beds evidence of a complex series of quartz " stringers " carrying metalliferous ore in small quantity, and which invades the sandy rocks as a large network; this must again undeceive us as to the probability of any sedimentary beds occurring in the series.

6. As all derivatives of Section 3 merge into, and cannot be divided one from another, sand-beds, as indicating old land surfaces must be discarded. Then the alteration from peat soil, through the final phases of decomposing basalt, to where, at a greater depth, it is seen again in a state of exfoliatory decomposition, must convince

us that, apart from constantly recurring lava-flows, there was no interregnum of quietude between the outbursts, but that basaltic (and doleritic) lavas flowed fast on the heels of a previous—and perhaps still—molten-flow.

The difference in weathering aspects is probably a clue to the study of the mineral composition.

With respect to Section 4 it would appear that the whole series of beds in the locality was undergoing a movement of complete reversal of position, and that the now basal sheet will take later the position of the former surface layer—this, then, being underneath.

Intrusive Sills are common in the region, but the petrographer can determine their nature. In Mull there exist intrusive sills and dykes of felsophyre, black rhyolite, olivine-dolerite and a doubtful rock with granophyric structure. None of these come into the present inverted structure, and no dykes, acid or basic, can be recognised here.

We are now on the fringe of research work which will never obtain finality, and which must be essentially of a chemical and petrological nature; where discrimination should obtain between inland and coastal weathering.

Adopting unaltered basalt beds as the normal, and accepting the fact that any other beds are deviations from the normal, a few points only are necessary to suggest the limits of this communication.

In Section 1 and 2 the soft decomposing bands represent perhaps a higher percentage of included water, and probably more lime than is included in the principal beds.

In Section 3 the differentiation of the heavy minerals in the exuded mother-liquor would seem to vary greatly from bed to bed. The fissility of the top bed is difficult to understand. But the limonite nodules in beds 4 and 6

appear to be the residual from either gas vesicles with infiltration of iron after ferro-magnesian minerals or olivines, giving place to hematite, with subsequent hydrated limonite. The serrated band (5) has some reason for exhibiting angular quartz crystals. These are secondary, and are clearly *in sitû* as the remains of drusy structure in original cavities in the basalt. In the sandy sheets analysis shows angular quartz grains in a band of nearly 60 per cent. of ferric oxide, and some white powder resembling clay, or kaolin. The analyses show no trace of humic acid or remains of plant life. Where true clay occurs it is this white powder stained with iron,—the final period of decomposition; and, in the field, it is quite possible to study the insensible gradations of chemical decay, however crude these sketches may represent them.

These facts related, conclusions are more or less obvious, and it would seem from evidence of the rock-masses themselves that there must be differences in mechanical and chemical composition of many of these sheets, which can only be determined through weathering agencies, and upon closer study it is not impossible that the extremely weathered beds should prove to be more basic than the basalt, and in places even ultra-basic.

In conclusion, the more acid the basalt beds the greater their invulnerability to weathering, but as they approach the ultra-basic condition atmospheric conditions then enter upon their most powerful phase.

The dissolution of all cosmic matter and the inevitable reduction of rocks in time is clearly demonstrated by these four exposures.

THE MINERALOGICAL CONSTITUTION OF THE STORETON SANDSTONE.

By J. Lomas, A.R.C.S., F.G.S.

The ridge of high ground extending from Bidston Hill southwards to Storeton owes its existence to a capping of Keuper Basement Beds. These have resisted the forces of denudation better than the soft and more friable Bunter fringing the ridge on both sides. The Basement beds thicken towards the South. At Bidston, Oxton and Prenton they seldom reach 30 feet in thickness, while at Storeton they are quarried to a depth of more than 110 feet.

Pebbles of quartzite, lydian stone, chert and other rocks occur near the base of the Keuper along with numerous rounded masses of Marl. At the actual base the marl forms an almost continuous band, and this being impervious to water soaking through the sandstone from above, gives rise to a line of springs. Hence the Keuper, as a rule, is damp, while the underlying Bunter is dry. But the circulation of water through the Keuper has produced other effects. Secondary quartz, barytes, oxides of iron and cobalt, and other minerals have grown in the interspaces between the grains of sand and rendered the rock more compact and durable, while the Bunter below remains with its grains incoherent or only very slightly cemented. At Storeton, beds of marl occur in the Keuper itself. In the quarry worked by Mr. C. Wells on the east side of the road, one of these occurs at 50 feet and another at 80 feet from the surface. The upper one is double in places, but in the north-west corner of the quarry, where the rock is being worked, the two bands have fused into one. This band is the celebrated footprint bed.

With a view to ascertaining the possible origin of the sand, samples were taken of the rock, as exposed in Mr. Wells' quarry, at nine different horizons, and were subjected to a careful mineralogical examination. In order to concentrate the rarer minerals the samples, after being reduced to separate grains by gently rubbing one piece against another, were fractionated by heavy density fluids. The results obtained are given below.

1. *Specimen taken 10 feet below surface.*

The rock is soft and porous, light brown in colour, with irregular streaks more deeply stained.

Quartz.—Rather coarse grains from 1 mm. to 1·5 mm. in diameter, well rounded and showing no signs of secondary crystallisation. The grains are clean and quartz dust is absent.

Felspar.—Very few grains—mostly kaolinised. With a lens the decomposed felspars can be seen in a hand specimen.

Mica, tourmaline, ilmenite, leucoxene with fresh anatase round the borders and zircon (·5 mm. in diameter) make up the rarer constituents. Chert grains also occur.

2. *30 feet from surface.*

The quartz is very uniform in size of grain, ranging from ·5 to ·7 mm. in diameter. Quartz dust in the form of irregular splinter resembling those described by Messrs. Dickson and Holland,* are very plentiful. Some have curved faces as though they had been moulded on a rounded grain and crystal facets are common. While the quartz grains show numerous inclusions, the splinters are always clear. It is highly probable, as suggested by Messrs. Dickson and Holland, that these represent portions of the secondary silica deposited on the grains and disengaged by reducing the rock to powder. Many of the

* Proc. L'pool Geol. Soc., Vol. VIII, Part 4, p. 447.

quartz grains have the secondary silica attached, and the outlines of the old battered grain can be seen through the covering of the new growth.

Flakes of felspar occur in much fresher condition than those in the beds above.

The other minerals occurring at this horizon are rutile, tourmaline, ilmenite with outgrowths of anatase, anatase enclosing rutile, and mica with inclusions of zircon.

3. *40 feet from surface.*

The minerals resemble those enumerated above. There is abundance of secondary crystallization round the quartz grains and much quartz dust.

4. *50 feet from surface. "Footprint Bed."*

The marl occurring at this horizon is very thin, seldom reaching an inch in thickness, but it is very persistent and can be traced all round the quarry. It is pale blue in colour, very plastic, and weathers into a deep red colour. The sandstone immediately overlying the marl has a smooth surface, the interspaces between the grains having been filled with a thin iron scale. The scale has been examined separately and when the cementing iron oxide is removed by treating with hydrochloric acid, the residue is found to consist of sand grains exactly resembling those in the beds above. Heavier minerals such as zircon, rutile, tourmaline, anatase and barytes are exceptionally abundant, and much smaller than those found in other beds. It may be that these have been conveyed by circulating water from the upper layers and concentrated on the impervious marl.

5. *60 feet from surface.*

The rock is light brown, compact, and makes a good building stone. The quartz sparkles in the sunlight and almost every grain is covered by secondary growth. It

was possible to orient some of the grains by the occurrence of negative crystals in the interior, and the secondary silica was seen to be in crystallographic continuity with the original grain.

The quartz varies in diameter from ·5 mm. to 1 mm. and when clean has a distinct pink colour.

The felspars are fresh and mostly occur as cleavage flakes. Zircon, tourmaline, ilmenite and anatase were plentiful.

The rock as a whole is dry, false bedded, and contains a few clay inclusions and fine iron specks which stain the rock for a short distance round the grain.

6. *80 feet from surface.*

A thick marl band occurs at this horizon and can be followed in other quarries along the Storeton ridge for a distance of two-thirds of a mile. It varies in thickness from a few inches to two feet and in places a thin band of sandstone is enclosed. The sandstone in contact is coated with a smooth iron scale. No footprints have been found in association with the marl, but curious markings resembling the track of a crustacean occur on the smooth surface of the overlying rock. These are evidently casts of impressions made by the organism when crossing the soft marl. Pseudomorphs of rock salt occur occasionally. When freed from iron and examined under the microscope the "marl" is seen to consist very largely of exceedingly fine quartz dust, and it contains an appreciable amount of undecomposed felspar and an abundance of small flakes of mica. Strictly speaking it is not a marl at all, but a very fine grained sandstone. When mixed with water it is not plastic and breaks with a fibrous fracture.

The sandstone included in the marl is exactly of the same composition as that forming the bulk of the rock, but the grains are not coated with secondary silica and

they include fresh felspar flakes. An analysis of this included rock is given by Messrs. Dickson and Holland* which confirms the observations made above.

7. 83 feet 6 inches from surface.

This is a grey sandstone with much felspar. Secondary growth is seen on nearly every grain of quartz. Tourmaline, zircon, rutile, anatase and mica were found among the heavier fractions.

8. 100 feet from the surface.

The band of rock occurring at this depth is coarser than any of the other samples, the grains ranging from 1 mm. to 2 mm. in diameter. It is pink in colour and contains many flattened patches of blue clay.

The quartz grains are very well rounded and show very beautiful secondary growth. Felspars are abundant. Tourmaline, mica, zircon, rutile, and numerous grains of black chert are common.

9. 110 feet from surface.

A light grey, fine sandstone of very even grain. tourmaline, anatase, rutile, zircon and chert also occur.

Taken as a whole the composition of the sandstone is the same from top to bottom. It shows varying degrees of coarseness at different depths, but for the same horizon the grains are remarkably uniform in size. Quantitative estimates of the different minerals were not made, as it did not promise to yield useful results. Even in a hand specimen it is seen that there are bands where concentration of the heavier minerals has taken place, just as there are thin lines of almost pure ilmenite in the rippled surfaces of our local sand dunes. Generally speaking, the specimens from near the surface show signs of alteration since the deposits were laid down. The felspars are converted into kaolin and there is very little

* Op. cit., p. 445.

evidence of secondary crystallization. At greater depths and particularly below the impervious marls the minerals are chemically fresh. Samples of the underlying Bunter and the overlying Keuper Marls have been examined for the sake of comparison, and the same minerals were found to be contained in both. The Keuper Marls as developed in our neighbourhood would more properly be described as composed of quartz dust, as they contain very little clay, and calcareous material is almost entirely absent.

Compared with Triassic deposits in other localities such as Leicestershire* and the South of England** we note that garnets, which are plentiful in those localities, are entirely absent from the sandstones at Storeton. In the Keuper Marls of the West of England Dr. Cullis† has described dolomite as occurring in minute rhombohedral crystals. This mineral, too, appears to be lacking in our Trias although it is present as well as garnet in the sands of the Mersey. When we come to discuss the sources from which our Trias has received its materials these facts will be of the greatest importance, and may, perhaps, lead towards a division of our British Trias into defined areas fed from different sources. Before this is possible a great amount of work must be done in examining the constituents of the Trias from many localities, and the older rocks must be exhaustively studied to see whether they contain distinctive minerals which occur in the Trias.

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* T. O. Bosworth, Trans. Leicester Lit. and Phil. Soc., Vol. XII., Part I., Jan., 1908, p. 28.

** H. H. Thomas, Q.J.G.S., Vol. LVIII., Nov., 1902, p. 620.

† Brit. Assoc. Report, 1907.

ON A MARINE PEAT FROM THE UNION DOCK, LIVERPOOL.

By J. Lomas, F.G.S.

During excavations in the Union Dock on the Mersey Docks and Harbour Board Estate in the south end of Liverpool a very remarkable peat band was discovered. Reckoning downwards from a datum line three feet above Old Dock Sill a section showed:—

Sand with black carbonaceous bands ...	4 ft.
Peat	6 in.
Blue clay with rootlets	4 ft.
Sand with thin bands of peat	2 ft. 10 in.
Boulder clay	3 ft. 2 in.
Bunter pebble beds	8 ft. +

The upper peat was entirely composed of marine plants, laminaria predominating. On the fronds were numerous encrusting organisms, such as polyzoa, hydrozoa, the fry of young molluscs, etc.

The lower peat, while consisting mainly of marine plants, contained a few drifted pieces of oak and other land plants.

The sands accompanying the peat resemble those of the Mersey Bar, and besides the quartz which makes up the bulk of the deposit, contain zircon, garnet, tourmaline, dolomite, kyanite, rutile, staurolite, orthoclase felspar, biotite and muscovite, shell fragments, foraminifera, sponge spicules and polyzoa.

The deposit was probably accumulated in a sheltered bay in the old estuary of the Mersey.

The chief interest lies in the fact that peat may be formed from marine as well as from land plants.

POST-GLACIAL BEDS AT GREAT CROSBY AS DISCLOSED BY THE NEW OUTFALL SEWER.

By T. Mellard Reade, C.E., F.G.S.

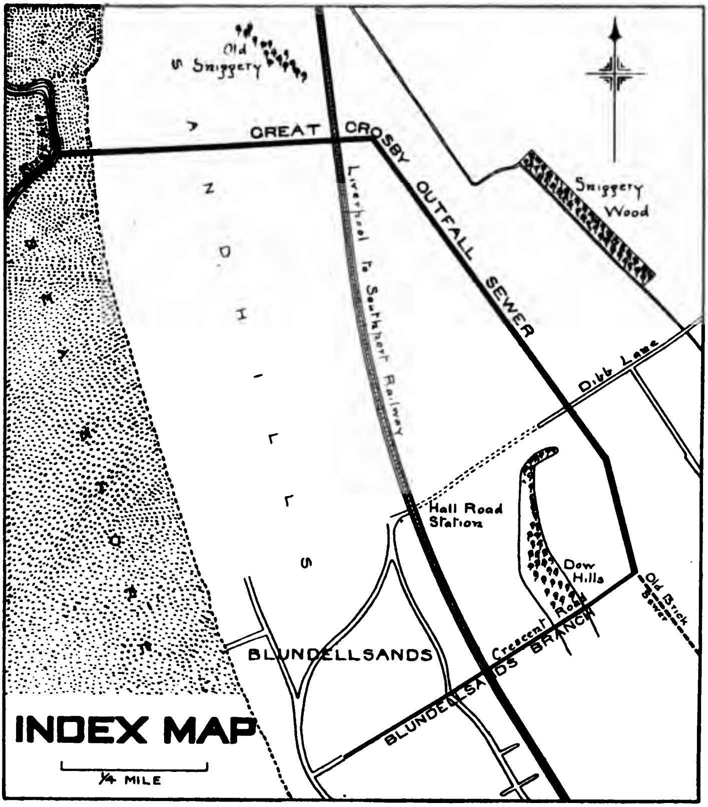
The construction of a new main outfall sewer for the township of Great Crosby by the District Council has given a unique opportunity for completing my Map of the South-West Lancashire Alluvial Plain which the Liverpool Geological Society published in their Proceedings in 1872.*

Course of the Outfall.

The outfall on the shore is situated about 1 mile 15 chains to the north of Crescent Road, Blundellsands.

The invert is at a level of 5 feet above ordnance datum, advantage being taken of a landward bend of the River Alt. From thence it is carried at a gradient of 1 in 700 for 360 feet on the foreshore, and then in one of 1 in 1,000 to the Lancashire and Yorkshire Railway, which it crosses close to the footbridge of the West Lancashire Golf Club. Shortly after crossing the railway it turns to the south-east, crossing Dibb Lane, and further south joins with the old system at the termination of the present brick sewer. The gradient of 1 in 1,000, except in the portion on the foreshore, is adhered to throughout, the total length being about 7,380 feet.

* The Geology and Physics of the Post-Glacial Period as shown in the Deposits and Organic Remains in Lancashire and Cheshire. Session 1871-72, pp. 36 – 88.



Geology Disclosed.

It will be seen from this description that although the trench is not anywhere very deep, what we get is a valuable continuous section from the shore across the sand dunes. As a matter of fact, we learn that, speaking generally, the beds cut through by the trench are first the pure blown siliceous sand, next blown sand with peaty matter staining it, giving a greenish hue; then intercalated thin beds of peat.

This assemblage rests upon a peat-bed continuous with the forest-bed on the shore, and below which are the upper beds of what I have termed the Formby and Leasowe marine or estuarine deposits.

The peat-and-forest bed can be seen exposed on the shore now—the excavation showed a variation of thickness of the peat from 1 foot 6 inches to 4 feet, the bed thinning out about 900 feet from the outfall.

Nearer to the railway the peat re-appears and is 2 feet thick at the point of crossing gradually thickening to 6 feet on the east side, at which thickness it continues to 420 feet from Dibb Lane. At 480 feet south of Dibb Lane the maximum thickness of 7 feet 6 inches occurred, resting upon Boulder Clay, and at 660 feet the peat ran out, still resting on the Boulder Clay and overlapping it about 180 feet, the remainder of the section was blown sand, green sand and Boulder Clay.

The Formby and Leasowe Post-Glacial beds were exposed by the trench from the outfall on the shore nearly to Dibb Lane, where the excavations left them. What their thickness is was not determined by these shallow cuttings.

A series of borings at Altcar, made by the Lancashire and Yorkshire Railway Company,* showed that they were there 38 feet thick, and rested upon Boulder Clay.

Later borings on the site of the new fort, near the Alt mouth, north of Crosby outfall, penetrated the Boulder Clay 25 feet 6 inches below the surface.†

That these Post-Glacial beds are part of the alluvial sheet of clay and silt underlying the peat-and-forest bed between Crosby and Southport is incontestible, and that

* See my Paper on "Some Borings at Altcar." Proc. of L'pool Geol. Soc., 1903-04, pp. 359—369.

* This information was kindly supplied me by C. B. Travis, Esq., from whom we shall, I hope, get full details.

they are marine or brackish water deposits is equally clear; single valves of *Tellina balthica* and *Cardium edule* were to be seen in the stuff (silt) thrown out of the excavation.

This very considerable deposit varies from an exceedingly fine clay to a sandy silt, and the profusion of foraminifera in some of the beds is remarkable. Sections were taken and noted at various points in the trench, but it is unnecessary to give more than the leading ones in this paper.

At 560 feet from outfall, *surface level about 22 feet above O.D.*, there were 4 feet of yellow blown sand, 2 feet of green sand, 2 feet 6 inches of peat. The rest of the excavation was in about 10 feet of silt, unbottomed, containing beds of a more clayey nature. This point is landward of the sand dunes, and is much eroded by the wind. The dunes where crossed by the line of trench were about 30 feet high above the general surface level.

At about 980 feet from outfall the section showed, underlying the sand dunes, varying sandy beds of yellow, green and brown colours. It looked as if this portion of the deposit had been subjected to sub-aerial influences and perhaps partial re-arrangement by water, salt or fresh, though consisting mostly of blown sand.

The top of the series appeared to be about 20 feet above O.D. Proceeding eastwards the peat bed re-appears, and at manhole No. 6, about 1,050 feet west of the Lancashire and Yorkshire Railway, it is 1 feet 9 inches thick, the surface of peat being about 13 feet above O.D.

At a point about 480 feet west from the railway a bone was found in the sand about 15 feet above ordnance datum. This proved to be the jaw-bone of a young horse.* The peat was here 2 feet 6 inches thick, the surface being about 12 feet above O.D.

* Determined by the Liverpool Museum Officers.

The best section occurred at the manhole No. 12, west side of the railway, near to the boundary.

The following are the details:—

Details of Section of Manhole No. 12.

SURFACE LEVEL ABOUT 25·5 ABOVE O.D.

Yellow Sand	6 ft. 6 in.	Pure blown sand (siliceous).
Green Sand	3 ,, 3 ,,	*Sample No. 1.*
Black Sand	0 ,, 6 ,,	*Sample No. 2.*
Peat	2 ,, 0 ,,	No sample taken. Surface of peat about 15 ft. 3 in. above O.D.
Silt and Clay	7 ,, 4 ,,	*The sample No. 3 is from the top* of this deposit (Formby and Leasowe beds). *Sample No. 4 from the bottom of excavation, about 5 ft. 9 in. above O.D.*
Total	19 ft. 7 in.	(The assemblage of silt beds was not bottomed).

The whole of these samples, Nos. 1, 2, 3, 4, were submitted to Mr. Joseph Wright, F.G.S., of Belfast, who kindly examined them for foraminifera.

I am much indebted to his help, which has been invaluable in enabling me to ascertain the characteristics of the deposits.

Mr. Wright's report is as follows:—

GREAT CROSBY OUTFALL SEWER.

Sample No. 1.—"Green Sand." Very fine siliceous sand, somewhat dirty, with turfy matter. Weight of sand, 27·3 oz. troy, no coarse, not washed.

Trochammina inflata (Montag.)—One specimen.

Cassidulina crassa (d'Orb.)—One specimen.

Nonionina depressula (W. & J.)—Two specimens.

Sample No. 2.—"Black Sand." Very fine siliceous sand, the black colour being due to the quantity of turfy matter in it. Weight of sand, 11·7 oz. troy, no coarse, not washed.

Nonionina depressula (W. & J.)—One specimen.

A few specimens of *Diffulgia* were also met with.

Sample No. 3. "Silt, below Peat." Very fine siliceous sand, dirty with turfy matter. Weight of sand, 27·6 oz. troy, no coarse, not washed. No foraminifera.

Sample No. 4. "Silt, bottom of trench." Very fine sand with turfy matter. Weight of sand, 24 oz. troy; after washing, 20 oz.; no coarse; foraminifera abundant.

Miliolina fusca (Brady)—Rare, specimens small and chitinous.

Trochammina inflata (Montag.)—Common.

Trochammina var. macrescens (Brady)—Common.

Verneuilina pygmæa (Egger)—Very rare.

Bulimina pupoides (d'Orb.)—Rare.

B. elongata (d'Orb.)—One specimen.

B. marginata (d'Orb.)—One specimen.

B. fusiformis (Will.)—Very rare.

B. elegantissima (d'Orb.)—Rare.

Bolivina punctata (d'Orb.)—One specimen.

B. variabilis (Will.)—Rare.

B. plicata (d'Orb.)—Rare.

B. obsoleta (Eley) ?—One specimen.

Cassidulina crassa (d'Orb.)—One specimen.

Lagena globosa (Montag.)—Very rare.

L. lævis (Montag.)—Very rare.

L. lævis var. clavata (d'Orb.)—Very rare.

L. lineata (Will.)—One specimen.

L. semistriata, Will.—Rare.

L. sulcata (W. & J.)—Rare.

L. Williamsoni (Alcock)—Rare.

L. squamosa (Montag.)—One specimen.

L. hexagona (Will.)—Rare.
L. marginata (W. & B.)—Very rare.
L. lucida (Will.)—Rare.
L. fasciata (Egger)—One specimen.
L. fimbriata (Br.)—Two specimens.
Nodosaria obliqua (Linné)—One specimen.
Cristellaria rotulata (Lamk.)—One specimen.
Polymorphina gibba (d'Orb.)—Very rare.
P. rotundata (Born.)—One specimen.
Globigerina bulloides (d'Orb.)—Rare.
G. æquilateralis (Br.)—One specimen.
Orbulina universa (d'Orb.)—Frequent.
Patellina corrugata (Will.)—One specimen.
Discorbina obtusa (d'Orb.)—Frequent.
D. globularis (d'Orb.)—One specimen.
Truncatulina lobatula (W. & J.)—Rare.
Rotalia Beccarii (Linné)—Frequent.
Nonionina depressula (W. & J.)—Very common.
N. orbicularis (Br.)—One specimen.
Polystomella striatopunctata (F. & M.)—Very common.
P. arctica (P. & J.)—Rare.
P. macella (F. & M.)—One specimen.

This gathering contained many rare and interesting forms, the most noteworthy being *Verneuilina pygmæa*, *Bulimina elongata*, *Lagena fimbriata*, *Globigerina æquilateralis* and *Nonionina orbicularis*—the last three have only been recorded as recent British species from gatherings taken off the west coast of Ireland. Amongst the microzoa were also a few broken ostracoda and a number of very minute sub-ovate sponge spicules.

At a distance of about 200 feet east of the eastern boundary of the Lancashire and Yorkshire Railway the section cut through was:—

SURFACE LEVEL ABOUT 20 FEET ABOVE O.D.

A.	Yellow Sand..................	3 ft. 6 ins.	
B.	Green Sand	2 ,, 6 ,,	
Bb.	Peat	6 ,, 0 ,,	
C.	Clay ....about	1 ,, 0 ,,	*unbottomed.*
	Total	13 ft. 0 ins.	

Of these beds Mr. Wright says:—

A.—"Yellow Sand." Fine sand with broken shells. Weight, 27·6 oz. troy, not washed, coarse none. Foraminifera rare, fairly large in size, but in poor condition.

Polymorphina lactea (W. & J.)—Very rare.
Discorbina rosacea (d'Orb.)—Frequent.
D. obtusa (d'Orb.)—One specimen.
Truncatulina lobatula (W. & J.)—Rare.
Rotalia Beccarii (Linné)—Rare.
Nonionina depressula (W. & J.)—Rare.
Polystomella striatopunctata (F. & M.)—Rare.

B.—"Green Sand." Very fine sand. Weight, 26·1 oz. troy; after washing, fine, 25·5 oz., coarse none. Foraminifera very rare.

Truncatulina lobatula (W. & J.)—One specimen.
Nonionina depressula (W. & J.)—Rare.
Polystomella striatopunctata (F. & M.)—Rare.

The foraminifera were in better preservation than in the previous gathering; besides the foraminifera there were also two broken valves of ostracods, one broken spine of an echinus, and a number of the nucules of Chara.

Bb.—Peat not examined microscopically.

C.—"Clay." Very fine clay, dirty, with peaty matter. Weight, 21·1 oz. troy; after washing, fine, 9 oz., coarse, none. Foraminifera abundant.

Trochammina inflata (Montag.)—Very common.
T. *var. macrescens* (Br.)—Very rare.

Bulimina pupoides (d'Orb.)—Rare.
B. marginata (d'Orb.)—Very rare.
B. fusiformis (Will.)—Rare.
B. elegantissima (d'Orb.)—Rare.
Bolivina variabilis (Will.)—Rare.
B. dilatata (Rss.)—One specimen.
Textularia globulosa (Ehr.)—One specimen.
Cassidulina crassa (d'Orb.)—Rare.
Lagena globosa (Montag.)—One specimen.
L. lævis (Montag.)—Rare.
L. var. clavata (d'Orb.)—Rare.
L. semistriata (Will.)—Very rare.
L. sulcata (W. & J.)—One specimen.
L. lucida (Will.)—One specimen.
L. orbignyana (Seg.) ?—One specimen.
Nodosaria sp.—One specimen.
Uvigerina angulosa (Will.)—Very rare.
Globigerina bulloides (d'Orb.)—Frequent.
Orbulina universa (d'Orb.)—Frequent.
Discorbina obtusa (d'Orb.)—Common.
Truncatulina lobatula (W. & J.)—Very rare.
Rotalia Beccarii (Linné)—Common.
Nonionina asterizans (F. & M.)—Common.
N. depressula (W. & J.)—Very common.
Polystomella striatopunctata (F. & M.)—Common.
P. macella (F. & M.)—Very rare.

In this clay there occurred numbers of very minute ovate sponge spicules, also one specimen of a triradiate spicule.

Several other silty, clayey and sandy beds from two other sections were carefully examined, but it will be unnecessary to describe the result, as they are more characteristically shown in those already given.

The following are sections of the strata taken in the remaining portion of the sewer trench.

It was not thought necessary to make a microscopical examination of the specimens, their character being similar to those already described.

At 420 feet north of Dibb Lane.

SURFACE LEVEL 19 FT. 9 IN. ABOVE O.D.

Strata......................	0 ft. 9 in.	Soil.
	1 ,, 9 ,,	Yellow Sand.
	3 ,, 0 ,,	Green Sand.
		Peat below (not bottomed, say about 6 feet thick).

At 480 feet south of Dibb Lane.

SURFACE LEVEL 21 FT. 6 IN. ABOVE O.D.

0 ft. 9 ins.	Soil.
2 ,, 1 ,,	Yellow Sand.
0 ,, 3 ,,	Band of Clayey Sand.
0 ,, 8 ,,	Green Sand.
	Peat, 7 ft. 6 in., resting upon boulder clay and sand.
	Peat ran out at 660 feet south of Dibb Lane, resting on the Boulder Clay, and overlapping it 180 feet.

At 1,080 feet south of Dibb Lane.

SURFACE LEVEL 24 FEET ABOVE O.D.

0 ft. 9 ins.	Soil
4 ,, 6 ,,	Yellow Sand.
0 ,, 5 ,,	Black Sand.
1 ,, 5 ,,	Silver Sand.

Boulder Clay below, in which occurred a pocket of gravel and comminuted shells.

The ground continued of a similar nature up to the junction with the old brick sewer and Blundellsands branch.

Results.

This section is important, as it shows the connection of the inland peat with the peat-and-forest bed on the shore.* The peat and peat-and-forest bed seem to exist as a sheet under a very large area now covered with blown sand and dunes.

At the time of the last subsidence the sea gradually encroached on the land, and the coastal margin was brought within a distance at which the sand from the shore could be blown on to the moss lands. The growth of this sand barrier backed up the inland waters, hence the origin of the meres, which formerly existed along this coast.

It is satisfactory to find that the observations described in this paper prove the substantial accuracy of the maps and sections and geological classification of my original paper on the physiography of the West Lancashire Coast, † notably the extension of the Formby and Leasowe beds, and the proof of their estuarine origin is complete.

Taking a wider view, it is most interesting that deposits of an identical character are to be found underlying similar peat beds all round the British Isles. The proofs of extended land movements are scattered over the whole coastal plain. Those interested I would refer to the Report of the Royal Commission on Coast Erosion, Appendix No. XXII., where I have stated the results of my researches and given the evidences of the geological changes that have taken place in Post-Glacial times in South-West Lancashire and adjoining areas.

In conclusion, I must express my thanks to Mr. Watkin Hall, the engineer who is carrying out the work,

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* See On a Section of the Formby and Leasowe Marine Beds, &c.—Proceedings of L'pool Geol. Soc., Vol. iv., Part 4, pp. 269—277.

† The Geology and Physics of the Post-Glacial Period, &c., 1871.

for the facilities he has given me to inspect the sections as exposed, and, further, for the ready help of his assistant, Mr. J. A. Wright, in recording accurate information and levels of various beds and securing specimens.

APPENDIX.

Since the foregoing notes were written the Blundellsands branch sewer has been commenced.

This sewer connects with the main outfall at its junction with the old brick sewer, and the trench proceeding due west cuts transversely across the Dow Hills. The Boulder Clay occurred capped with green sand and yellow blown sand for a portion of the way to Dow Hills, but near the centre of the dunes these were underlain by first a peaty soil bed with tree stumps resting upon a thin stratum of blue clay and a plastic brown clay, which in turn doubtless lies upon Boulder Clay, but this was not actually proved. The total length of this Blundellsands branch will be 3,195 feet, but in consequence of the rising gradient of one in 550 to Nicholas Road, its termination, the excavations are unlikely to disclose much new information.

LATER NOTE.—This prediction proved true, and the sewer is now wholly in sand.

The following is a section of the sewer trench where it crosses Dow Hills, giving the levels of the tops of the beds above O.D. (To get the thickness of the beds it is only necessary to deduct the lower figure in each case from the one above it.)

SECTION THROUGH MIDDLE OF DOW HILLS.

Yellow Sand, top of Hills	about	40	feet	above O.D.
Green Sand	,,	21·9	,,	,,
Peaty Soil Bed	,,	17·9	,,	,,
Blue Clay	,,	16·6	,,	,,
Bottom of Excavation	,,	14·0	,,	,,

Note on Blown Sand.

With the object of ascertaining whether distance from the shore had any effect on the character of the blown sand, especially as regards building purposes, my firm took two samples of sand—one from near Mariners Road, Blundellsands, 1,300 feet from the shore, the other at Dow Hills, 3,000 feet from the shore. These samples were submitted to Mr. Philip Holland, F.I.C., who reported that there was no appreciable difference between them in the amount of salt contained, which was negligible, and that the wind did not appear to have exerted much sifting action, the grains from the Dow Hills being on an average slightly finer and the mineralogical character identical.

SOME MARKINGS, OTHER THAN FOOTPRINTS, IN THE KEUPER SANDSTONES AND MARLS.

By Henry C. Beasley.

(*Read* 14*th January*, 1908.)

Besides the footprints, our Keuper Sandstones—and more particularly the footprint beds—formed under conditions favourable to the preservation of impressions of all kinds, present us with a great variety of markings for which it is more or less difficult to account. At one end of the series are some that may with tolerable certainty be said to be of organic origin (such as tracks of invertebrates, and, rarely, impressions of plants), and at the other pseudomorphs of chloride of sodium certainly inorganic, but the line between the inorganic markings and the organic is very difficult to determine—for instance, between some plant forms, and markings due to running water. Such troublesome fossils are not confined to the Trias. In a corner of one of the palaeontological galleries at Cromwell Road is a case containing markings of inorganic origin mostly simulating more or less closely, organic forms from various formations. In many cases the probable mode of origin is indicated, and the too ardent fossil collector might avoid many disappointments if he gave a few minutes to the study of the contents of the case. The markings we are dealing with may, for convenience, be grouped as—

I.—Tracks of invertebrates.

II.—Casts of plants and markings simulating vegetable forms.

III.—Parallel rectilinear and concentric curved markings.
IV.—Irregularly curved markings.
V.—Markings resembling the integument and coverings of animals.
VI.—Ripples, wrinkles and desiccation cracks.
VII.—Rain pittings and similar spots.
VIII.—Pseudomorphs.

This is a formidable list, and as I cannot hope to deal with the whole of it this evening I shall confine myself to the first three or four groups, and illustrate them mainly by examples from Cheshire and the adjoining counties.*

The markings usually supposed to be the tracks of worms are very common in our sandstones. They so nearly resemble in many ways the tracks left by our common earth-worm that there would seem to be little room for doubt, but it is advisable not to jump too hastily at any conclusion, however plausible.†

The curves are sharper and the sinuosities rather more intricate than is the case with our recent tracks. They are also found in beds in the upper Keuper associated with pseudomorphs that show the presence of considerable salinity.

Besides the tracks, we find on the upper surfaces of the beds of sandstone what appear to be the casts of undigested portions of the soil passed through their alimentary canal just as they are found at the mouths of recent worm-holes. They are, however, much less

* A. G. Nathorst's important paper, "On some tracks of invertebrates and their palæontological bearing," in K. Svenska Vet., Akademieus Handlingar, Band XVIII., No. 7, Dec. 1880, contains descriptions and figures of the actual tracks made by a number of recent named invertebrates, with references to the work of others. Like Prof. Hughes' later paper referred to below, it is indispensable to the student of fossil markings. Unfortunately I was unable to see it before this paper was read, but I have referred to it in foot notes.

† Nathorst, op. cit., Plate VII., Fig. 1.

curved, and may possibly be the coprolites of other animals.* Traces of their burrows have also been occasionally observed, but not clearly in connection with the tracks.

In the recent exposure of the footprint beds at Storeton we have casts of these burrows vertical and horizontal in the clay underlying the footprints. The casts of the horizontal burrows in the clay are, of course, detached from the sandstone, and are usually lost, and escape observation during the weathering away of the clay, but we were fortunate enough to see some when first uncovered but still in situ. There are also casts in the clay of vertical burrows passing up into the sandstone above, but no connection with the horizontal ones has been seen. On the under surface of the stone there are also hollows representing burrows into the sand; it would, therefore, appear that after the clay began to be covered with sand the burrowing was continued. The burrows seem to have been one-eighth to three-sixteenths of an inch in diameter—the vertical ones the larger. Similar horizontal burrows of rather less diameter were seen in a small quarry near Five Crosses, Frodsham.

It is not easy to distinguish between the tracks of small recent gasteropods and those of worms; generally, however, the lateral ridges are more marked in the gasteropod track; there is also a slight trace of a beading caused by the undulations of the gasteropod foot. These are often strongly marked when freshly made, but soon become indistinct on a very wet surface and would perhaps not be preserved in the natural cast, and I should be inclined at any rate to attribute to molluscs the broader tracks, some of which are half an inch or more in width. There was one particularly well marked on the largest

* Where the castings are ejected under shallow water, they have been observed to be quite straight.

of the slabs at Storeton in 1906. Some similar broad markings have been supposed to represent the drag of the tail of some vertebrate, but I think that there would in that case be some longitudinal markings, the effect of drag, which I do not notice in those now considered. A vertebrate tail of that size would probably present some small projections, scales for instance, which would leave some mark. It is well to remember that beads, scales or dots of any sort denote absence of movement, whilst longitudinal markings are frequently the result of drag. Probably we have here tracks of both molluscs and worms, and it is to be hoped that further research may enable us to distinguish one from the other.

The most important of invertebrate tracks are those discovered by Mr. W. Mawby on the upper surface of some yellowish fine-grained sandstone at the north-east corner of the old north quarry at Storeton. A fine specimen of these was presented by him to the British Museum, and is exhibited in one of the wall cases near the Triassic footprints. Other specimens are in his own collection, and, I believe, in the hands of some other members of this Society. In a specimen in my own collection the track consists of a row of crescentic pits just large enough to be seen easily with the naked eye. Each pit has one side bounded by a minute elevation, the same side in each pit, so we may consider this the posterior margin. It would appear that the pit is in fact a foot-print, the elevation being caused by the backward pressure of the foot of the animal. At a distance varying from 1 to 1·5 cm. is another similar row, roughly parallel but more indistinct. In the British Museum specimen, and in some of the others, the rows are more distinct and parallel.*

* See Prof. T. M. Hughes, "On Some Tracks of Terrestrial and Fresh Water Animals."—Q.J.G.S., Vol. xl., p. 178. Also Nathorst, op. cit., Plate IX., Fig. 3.

Natural Casts of Plants.—Casts of stems of calamites and equisetiform plants are frequently reported as having been found. There is one from this district about which little doubt has been expressed, and that is the specimen of Equisetes keuperina (Morton) from Lower Keuper of Storeton, now in the Free Public Museum. The flutings, nodes and upper termination are all perfectly distinct. I believe that in Mr. Morton's own collection there were other stems from Storeton showing nodes.

In my own collection a thin slab of light brown, fine sandstone from Flaybrick (east side Tollemache Road), showing a flattened stem about 2·5 cm. broad throughout the length of 30 cm., with one very ill-defined node. There is an appearance of other nodes, but this is probably due to small faults or cracks in the stone. The longitudinal flutings are clearly marked, and there are on either side of what look like long narrow leaves 4 cm. long by 0·5 cm. broad. A similar narrower marking minus the node and leaves crosses the stone obliquely.

Another stone with the flutings but without any sign of nodes or leaves was found in some moderately coarse grey sandstone a few feet above the conglomerate at the base of the Keuper on the site of the present hospital at Flaybrick Hill; the width of the stem is about the same as in the larger of those in the fine-grained slab just described, found on the other side of the road.

The absence of distinct nodes or other traces of structure or of any remains of carbonaceous material calls for the greatest caution in dealing with anything that looks like the cast of a plant.

Within the last few days I have seen on a slab recently raised at Storeton a larger group of similar markings to those described above, with the nodes better defined.* (Pl. IX.)

* This has since been acquired by the Liverpool Free Museum.

There are several specimens to be found in collections labelled "Plant remains from New Red Sandstone" that often consist of a main trunk something over a foot long, tapering more or less to one end with longitudinal ridges and grooves, and on either side is an appearance of an irregular row of narrow leaflets. At the smaller end the ridges separate into separate rods, looking as if that end had been crushed. Two slabs at Warwick may be cited; one is from Coten End Quarry on the outskirts of the town and the other from Lymm, Cheshire.

The British Museum (R 730) has one rather larger but resembling the Warwick ones, except that there are rows of what seem to be scales on the ridges at the broader end; at the other the ridges pass into rods as in the Warwick example.* The appearance of rods and also of the leaflets might be produced by water, as I shall show presently, but the scales, or at any rate protuberances, are not easily explained. It has been suggested that the mark in the British Museum example was caused by the tail of some animal; it is certainly associated with footprints, but their relative position does not favour the idea of any connection.†

I have taken the equisetiform and other like plants first, as at present this class of plant is thought likely to occur under what are supposed to have been the conditions of the Triassic period, but something over half a century ago only a marine origin was imagined for the Trias, and consequently fucoids were looked for. Hence we have a lithograph signed "H. Dirks, 1837," of what is described as "A gigantic fossil fucus in the New Red Sandstone at Woodside." Apparently from the scale it covers a slab

* G. H. Morton, Geology of Liverpool Appendix, Plate XXII.

† I have since seen on the shore at Leasowe stream markings similar to Plate II., with regular markings along the channel apparently made by some Amphipod taking advantage of the stream to overtake the receding tide.

14 feet by 10 feet. Miss Morton is the fortunate possessor of a copy of the lithograph, and was good enough to exhibit it to the Society some years ago, and it is by her very kind permission I am able to show it to-night.

Then we have two or three lithographs issued by the Liv. Nat. Hist. Soc., 1839/41, described by me in our Procs., Vol. IX, p. 284.

All these certainly have in form many resemblances to fucoids, but they may also be due to inorganic causes.

In 1839, about the time the Liv. Nat. Hist. Soc. was issuing its lithographs, Sir Roderick I. Murchison, in his Silurian System, mentions and figures a supposed impression of a plant from the New Red Sandstone. He says (part I, page 43): "I am as yet acquainted with one plant only found in strata of this age," (sandstone and quartz conglomerate of New Red Sandstone), "at Liverpool, a specimen of which is in the Literary and Scientific Institution of that town." He then goes on to say that it has been examined by Prof. Linley and named "Dictyophillum Crassinervum," and is figured in Fossil Flora, Vol. III, p. 201. He adds a figure from a drawing prepared under Mr. Linley's directions, and then gives Linley's description: "The specimen is that of a leaf of considerable size, of which only the upper end remains, the end itself and all the margin being broken off. It bears a striking resemblance to the leaf of some of the thick-leaved cabbages." He then gives measurements and details, and concludes: "In the whole specimen there is a good deal of irregularity of arrangement in the parts and a greater want of symmetry than is usual in leaves." I do not think the vegetable origin is at all clearly marked, but it is hardly fair to express an opinion in the absence of the original fossil, and I have been unable to trace it in either the Liverpool or Bootle Museums.

Having described the real and supposed plant remains, I will next describe some of the forms of sculpture in soft sand caused by running water, which in some respects resemble some of the forms we have been dealing with.

A convenient place for observing these is along the shore between Wallasey and Hoylake, where broad and extremely shallow streams of fresh water from the land are often met with flowing over a very slightly sloping surface of sand, as well as streams of salt water from the receding tide (Pl. X). The results in each case are the formation of plant-like forms of sculpture. I have some photographs here, and in them you will see some resemblance to the fossils we have been considering. In particular I would point out the fringe of small channels on the sides of the larger ones, resembling the leaflets on several of the supposed fossil plants. Two of the most interesting forms I was unable to photograph, not having a camera with me when I saw them, but I took notes of them and rough sketches.* In February, 1904, after a severe frost and a good deal of snow, I noticed many curious markings, one to two feet long, each consisting of a deep groove widening seawards, bounded on each side by a rounded ridge and terminating seawards in a talus formed of the material removed from the groove. The termination landwards was a tuft of small grooves, evidently water channels. These forms often combined both longitudinally and transversely with one another, making elaborate and quite beautiful patterns. In December, 1906, I saw the same kind of marking just outside the then margin of a sheet of surface water flowing over the sand. It was rather larger (3′ 6″) than those previously seen, and

* Mr. W. T. Haydon has kindly shown me a sketch in his note book of a similar marking noted in Kent many years ago.

instead of the termination landwards being a tuft, the small end of the marking was fringed on each side with a row of minute channels; in this case, having developed so far, the supply of water diminished and it was left isolated and symmetrical, but the part of the shore still covered by water was an intricate network of similar forms. Had this isolated example been found in a fossil state, it would readily have been accepted as a fossil plant or portion thereof.

Having seen these recent forms, we may pass again to more ancient ones.

The fossil forms most likely to be caused by running water are those I have called for my own convenience flame forms. They are pointed convex markings, generally in low relief, sometimes only three times as long as broad, and at others extending to a considerable length, and generally the median line is slightly undulating, suggesting some likeness to a flame. These simple forms are by no means confined to the Trias; I have some from the Skiddaw Slates. Although they are mostly very simple forms and readily accounted for as casts of the beginning of a channel, they are occasionally more complex. For instance, in a spoil heap below Beetle Rock, Runcorn, I found a piece of rock with a group of these markings in somewhat higher relief than usual. (Pl. XI, fig. 1). There were about 20 in all, varying in length from 4 cm. to 20 cm., and in width from 0·5 to 0·75 cm., preserving nearly the same width until near the termination, where they narrow to a point. They are subcylindrical in cross section, and somewhat undulating.

They take their origin in an ill-defined mass from which they radiate slightly, becoming soon clear of each other. Two of the larger ones appear to have broadened at their extremities but have been broken off; one shows distinctly a hollow about half its diameter, the other one

only shows faint indications of the same. The only one of the smaller ones that has been broken shows a hollow. Unfortunately, not having been seen in situ, we cannot say positively that the surface is that of the underside of the bed; we can only say that it has every feature of the underside in contact with a bed of clay. Among the longer rods are shorter ordinary flame-shaped markings, and there are various intermediate forms between these and the larger ones.

In the same spoil heap and at a short distance from it on a similar surface the flame form is associated with some club-shaped markings (Pl. XI, fig. 2). The largest club is about 1·25 cm. in diameter, the whole group covers 8 cm. by 5·5 cm. The largest club is between two flame-shaped marks of about half its length, which equals about 5 cm. Next comes a long stem between 6 and 7 cm. long, with part next the thickened end missing. The thickened end is only 0·75 cm. broad by 2 cm. long, somewhat cusp-shaped and bending to left; next to it is a similar head bending to right, stem very indistinctly marked. Then a straight, rather smaller head and indistinct stem, with a small flame-shaped mark on each side reaching about the level of the base of the thickened head. A certain amount of symmetry is here seen, except that the left club, &c., is so much larger than the right. The cusp-shaped form referred to we shall see later in another association, but at present we are concerned with the flame marks.

We have also the flame form associated with other markings on a much larger surface at Aughton (Lower Keuper Sandstone), and I show you on the screen a piece 38 cm. by 23 cm., and a smaller piece is on the table. The whole surface has the general appearance of the cast of the bottom of a stream course.

The flame-shaped markings are, as a rule, I think, due to running water, but the same form may be due at times to other causes (Pl. XII, fig. 1).

Connected with this group of forms we have noticed a cusp or crescent-shaped marking on one of the Runcorn fossils, a rod terminated by a definite cusp, but with no details. A mark of the same kind, but very clearly defined, was obtained from another part of the quarries there. It is triangular in section with a decided ridge along the centre line. It measured 5 cm. by 1·5 cm., and has a small projection about two-thirds along the inner side about 0·75 cm. (Pl. XII, fig. 2).

A pair of similar, rather smaller marks were found in the footprint bed cut through in making a sewer in Waterford Road when building began on Oxton Heath, the same bed in which Dr. Ricketts found what he believed to be casts of plants (Pro. Liv. Geol. Soc., Vol. V., p. 168). The two markings are somewhat symmetrically placed, the convex sides inwards. There is a similar small projection to that described on the convex side of one, and another on the concave side of the other, destroying the symmetry. A portion of what appears to be a third is on the farther margin of the stone. There are also some indistinct footprints and three longitudinal, rod-like markings the whole length of the stone, 4 or 5 mm. wide approximately parallel the other crosses them obliquely, the longitudinal ones pass beneath one cusp and the oblique one under the other. There are sundry other examples from Oxton Heath and elsewhere, but they throw no light on their origin (Pl. XII, fig. 3).

From the same sewer cutting I obtained a good-sized stone covered with footprints and other markings, organic or inorganic uncertain. Unfortunately in taking a cast of a portion of the surface the original was seriously injured: however, the cast of the injured part was perfect,

and I have managed to piece together a cast showing the whole surface.

I will now turn to a very different class of marking, somewhat difficult of explanation.

It consists of parallel lines in relief, the larger ones often rectangular in section with sides from one-eighth to half an inch across; others much smaller with a cylindrical section. They occur sometimes single, sometimes in pairs, but more often in considerable numbers. The breadth is constant, except where they sink into the surface of the stone and disappear.

In one instance, at Daresbury, we found the markings not straight but part of a large curve, the markings being exactly concentric. The outer mark was rectangular in section, and might be described as a fillet three-sixteenths of an inch wide, with a fine line incised along the upper side, then followed a flat surface two inches across and a rounded fillet one-eighth inch wide, with fine parallel flutings. This seemed part of a moulding $1\frac{1}{2}$ inches wide, bounded on the inner side by a rather smaller fillet, and between the two was a very slightly relieved moulding of a very broad triangular section (Pl. XIII).

Some years afterwards in the quarry at Aughton a number of instances of smaller straight parallel lines were found (Pl. XIV); on the largest the lines stretched across two-thirds the surface of the slab and then gradually died out against a slightly more elevated portion which represented a hollow in the original clay, where naturally any object dragged lightly along would cease to leave a trail. A close examination of the group of lines showed their general similarity to those of the Daresbury specimen, but on a much smaller scale. The fine flutings on the main ridges were common to both, and they probably had a common origin. There are no beadings or disconnected

ornament of any sort, so we may safely consider the probability of their resulting from something being dragged over the surface of the underlying clay, the overlying sandstone retaining a cast of the result.* I thought that they might be caused by the margin of the carapace of some Chelonian. At that time it was held that certain footprints were those of Chelonians, but now this is considered very doubtful, and the footprints in question are attributed to quite another family of reptiles. There is no reason, in the absence of any other explanation, why they should not have been made as I supposed, or by the protective covering of the ventral surface of some other animals. This is merely a suggestion. We have no footprints associated with these markings to help us. I have not been able to obtain anything resembling these from the European tortoises, but I have noticed certain streaks caused by the under-surface of small crocodiles.

Short bands, in low relief and similarly marked with line of flutings, have been seen at Alton and Codsal, in Staffordshire. These are about an inch long and occur again in the same line as would have been the case had the object causing them only occasionally come in contact with the surface of the clay. Short straight ridges are often seen connected immediately with the claws of footprints, and represent the drag of the claw when the foot is not lifted clear of the ground.

In other cases a confused mass of groups of concentric ridges are found, e.g., at Runcorn and Frodsham. They remind one of the marks of a broom on a carriage drive rather unskilfully swept. It is impossible to say whether they are caused by the movements of animals or by physical causes.

* Compare with Nathorst, op. cit., Plate IX., Figs. 4 and 5, of Algæ dragged on soft plaster; also with his Plate X., Figs. 4 to 6.

LOWER KEUPER, FLAYBRICK HILL.

SEA SHORE, HOYLAKE.

Fig. 2. Fig. 1.

Lower Keuper, Runcorn.

Vol. X. PLATE XII.

Fig. 1.—Caldy Grange Fig. 2.—Runcorn.

Fig. 3.—Oxton Heath.

DARESBURY.

VOL. X. PLATE XIV.

AUGHTON.

I have dealt so far with the four first groups mentioned in the introduction. The others, involving as they do the consideration of pressure, desiccation and chemical action, must be reserved for another occasion.

DESCRIPTION OF PLATES.

All the fossils figured are from Lower Keuper Sandstone.

Plate IX.—Part of a slab at Storeton (now in the Liverpool Museum), with casts of fragments of plants.

,, X.—Recent stream markings on sea shore at Hoylake simulating plant forms with fringes of leaflets along the stems.

,, XI.—Two examples of flame-shaped markings from Runcorn.

,, XII., fig. 1.—Simple flame-shaped marking from Caldy Grange Quarry.

,, ,, fig. 2.—Isolated crescentic marking from Runcorn.

,, ,, fig. 3.—Several imperfect crescentic markings associated with straight ridges somewhat triangular in section, Oxton Heath.

,, XIII.—Curved concentric ridges and mouldings from Daresbury.

,, XIV.—Fine parallel markings from Aughton.

ANALYSES OF LONGMYNDIAN ROCKS.

By

T. Mellard Reade, F.G.S., F.R.I.B.A.,

and

Philip Holland, F.I.C.

Last session (1906-1907) we contributed a paper to this Society entitled "Analyses of Ludlow Rocks," in which a series of representative specimens arranged in sequence "commencing with the Old Red Marl and working down to the Silurian," were analysed and dealt with.

We now propose to deal with a much older series of rocks, namely, the Archæans of the Longmynd. Having this object in view, and with the efficient aid of Mr. E. S. Cobbold, F.G.S., we collected the specimens enumerated and described in this communication.

Formerly the rocks of the Longmynd were classed as Cambrian, but now, by the general consent of geologists, they are considered to be Pre-Cambrian or Archæan. Compared or contrasted with the Ludlow group they present in the field very dissimilar characteristics being much folded and faulted. Compression, infiltration probably of dissolved silica and other agencies, have also hardened the once soft shales and clays. Mr. Cobbold, to whom we are much indebted for information in the field, says ("Church Stretton Geology," p. 70): "There are two striking features about the old rocks of the Longmynd —first the wonderfully straight and parallel lines that come out on the map when the various horizons are carefully plotted; and second the intense amount of fracturing along planes in many different directions The

regularity may be said to be too good to be true, for when an attempt is made to follow any individual bed along its strike it is found to disappear in a very few yards in a most provoking manner, and may not be seen again for a mile or two. In a few instances a bed may be followed on the ground for a hundred yards or so, but if the exposures of the associated rock are good enough, it may be seen to be constantly thrown this way or that by faults often nearly parallel to the strike. These features speak strongly of the packing that has gone on in these strata."

The specimens collected for analysis belong to the Lower Longmyndian group.* This series, Mr. Cobbold remarks, is "as a whole a slaty one, but grits and conglomerates occur and some of the beds appear to be genuine volcanic accumulations, while many of the finer slates contain flakes or pieces of previously existing rocks, suggesting the existence of active volcanoes at no great distance throughout the whole time of the deposition of the strata." p. 69.

An optical examination of thin slices of the included "flakes or pieces of rock" from this horizon would appear to be desirable, for it would show if their volcanic origin were well founded. We think our analyses will support this view in so far as chemical evidence alone can do so. The rocks evince a remarkable homogeneity of structure and mineralogical characteristic, and may well be one series of volcanic deposits.

Dr. Callaway, in a paper read before the Geological Society of London in 1886, showed that there were derived fragments in the Longmynd and newer Archæan rocks of Shropshire (Q.J.G.S., Nov., 1886, p. 481) which he has traced to their original home in adjacent lands. In a very typical plum-coloured grit from the head of

* As defined on page 72 of "Church Stretton Geology."

Carding Mill glen west of Church Stretton he found "volcanic materials of the usual type abundant." (p. 482.) Though the geologists who have studied the Longmynds differ as to the age and the divisions of geological time represented by the rocks, we do at any rate find a consensus of opinion as to their Pre-Cambrian age. To their structural characteristics and the lateral pressure which has folded the beds, as also to the partial metamorphism they have undergone, we may refer the remarkable regularity of the effects of denudation.

The smooth rounded green slopes of the Longmynd are beautiful and engaging features not often found in connection with very ancient rocks. Lateral pressure renewed from time to time has affected the mass with striking regularity. Again the jointing and faulting may be the effects of pressure on rocks that have become hardened, and, therefore, subject to fracture by packing with more argillaceous and softer rocks.

Although lithological difference is not generally considered an indication of relative geological age, the distinction between the highly folded rocks of the Longmyndians and the adjoining Silurians is so striking to an observer experienced in geological tectonics that he is justified in drawing the conclusion that the Longmyndian rocks are the older

That such an inference is a fair one we have confirmation by the late researches and surveys of Callaway, Lapworth, Blake and other geologists of eminence.

The present investigation was undertaken because we were unable to find a record of the chemical examination of Longmyndian rocks—a record it seemed desirable to have so as to compare typical Longmyndians with the Ludlow beds. An account of the latter was presented to this Society last session.

The work we have done must be regarded as of a pioneer character. It will be seen that although the rocks of the Longmynd differ among themselves microscopically and macroscopically, they yet present much agreement in respect of their ultimate chemical composition.

A reference to the Proceedings of the Liverpool Geological Society, Session 1906-1907, p. 205-206, will show that the analyses of the Ludlow rocks were made by the acid extraction method. For the Longmyndians on account of the hardness of most of the specimens, acid extraction was replaced by the usual fusion method, except for No. 7, a fine textured consolidated mudstone. The schemes of analysis, though dissimilar for the two sets of rocks, have, nevertheless, given interesting data of a general kind.

We will now consider the specimens in their order.

Nos. 1 and 2. The Buxton Rock from Castle Hill, weighed over 9 oz. It is a very hard greenish grey rock, quite homogeneous, with a clean smooth fracture and a specific gravity of 2·68. Reference to the Table of Analyses shows the composition to be that of a volcanic rock whilst the figures themselves suggest a rhyolite.

No. 3. A nodule belonging to the Stretton Shales, contains over 50 per cent. of carbonate of lime along with 1 per cent. of phosphate which, taken in conjunction with the presence of some carbon, would suggest an organic residue for the nucleus of the nodule.

Nos. 4 and 5. Gritty slate from below High Park. The analysis, as will be seen from the parallel columns of figures, is in some respects like that of a slate rock from Anglesey of which a description is given in the Proceedings of the Liverpool Geological Society, Session 1899-1900, p. 467.

	No. 4. Gritty Slate below High Park, Church Stretton, Shropshire.		No. 5. p. 467 *loc cit.* Slate Rock (crinkled) from Llanrhydroes, Anglesey, N. Wales.
Total SiO_2	62·05	......	61·65
TiO_2	0·49	......	0·70
Al_2O_3 ...	18·66	......	16·82
Fe_2O_3 ...	6·09	......	6·61
FeO	1·02	......	1·39
MnO	0·12	......	1·07
CaO	1·06	......	0·15
BaO	—	......	0·03
MgO	2·32	......	2·02
K_2O	2·80	......	2·90
Na_2O	2·12	......	3·36
SO_3	none	......	—
CO_2	none	......	—
P_2O_5	none	......	0·08
Combined Water and difference	3·27	......	3·22
	100·00		100·00

Although the chemical composition is similar, No. 4 is a finer textured rock.

No. 5. Longmynd from the dingle below High Park is of nearly the same composition as No. 4. Both 4 and 5 Longmynd in appearance and colour resemble the Anglesey rock.

No. 6. The Huxter Conglomerate. This specimen weighed over ½ lb. On breaking it up a few quartz pebbles of irregular form were set free. The largest measured 8×5 mm., whilst those of decreasing size measured across their longest diameter 6·0, 5·3, 4·6, 4·2, 3·7 down to 1 mm. Systematic washings of the crushings and siftings did not show any good spherical grains of

quartz, but gave abundance of flakes and splinters. Particles of felspar could also be identified. The almost spherical polished micro-pebbles common to river sands were not present so far as we could judge in the siftings and washings of this conglomerate.

No. 7. A purple shale from the Burway is a somewhat hard, very fine textured rock, and appears to be a consolidated mudstone The analysis was made by the acid extraction plan, an outline of which appears in "Sands and Sediments," Part III., Proceedings, Session 1905-1906, p. 145. We give below the analysis of No. 7 alongside that of a Ludlow rock, viz., No. 5 Old Red Marl from Sheffield and Turner's brick works, see "Analyses of Ludlow Rocks," Proceedings, Session 1906-1907, p. 199 and 205.

	No. 7. LONGMYND.	No. 5. LUDLOW.
Combined water and difference	3·19	3·87
Insoluble in Acid and Alkali	72·69	73·94
Soluble in Acid and Alkali:—		
SiO_2	7·30	8·90
TiO_2	0·35	0·16
Al_2O_3	5·84	5·19
Fe_2O_3	7·33	3·51
FeO	none	present
MnO	0·17	present
CaO	0·98	1·32
MgO	1·41	1·98
Alkalies	0·62	0·60
CO_2	none	0·53
SO_3	none	none
P_2O_5	0·12	trace
	100·00	100·00

No. 5 is somewhat the coarser, for the crushings (by pressure alone) did not entirely pass the 90-mesh sieve. There is an obvious similarity in composition here.

No. 8 in the Table is somewhat fissile. It is a Stretton shale and was collected by Mr. Reade from a house excavation above Halescroft. In colour as also in composition it resembles what is known as "second green Velenhelli" Welsh slate. Our specimen was more shaly than slaty, but the texture of the two rocks is about the same. (See Proceedings, Session 1903-1904, p. 112, and Table of Analyses.)

No. 9. A nodule in the Longmyndians showing cone-in-cone structure. Nearly three-quarters of it is carbonate of lime. The lower content of sand, and almost entire freedom from phosphate differentiate it from No. 3 nodule.

No. 10. The Batch Volcanics. A reddish brown conglomerate with a matrix of quartz grains of $\frac{1}{2}$ mm. and under. The matrix encloses angular and sub-angular pebbles measuring 4×4, $3\frac{1}{2}\times2$, 3×3, 3×2, $2\times1\frac{1}{2}$ mm. In addition were numerous greenish angular fragments of which one measured 6×5 mm. These fragments as they lay effervesced very slightly when touched with acid, whereas the matrix itself did not. The minute bubbles of CO_2, clearly visible with a lens arose from parts only of the surface of the fragments which themselves were not homogeneous.*

No. 11. Purple shale from above the Carding Mill. Like No. 4 this resembles slate rock in chemical composition. Evolved from fine sediment the material has not

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* Specimens of this bed from the Batch have been recently examined microscopically by Professor W. W. Watts, who described the rock as a volcanic grit or tuff, largely made up of Andesitic material.—Caradoc Record of Bare Facts, 1894, 95, 96.)

undergone the dynamic agencies required to convert a sediment to a true fissile state. The constituents are there in right proportion but the rock lacks those physical properties which distinguish true slate from shale.

Description of the Specimens of Longmynd Shales.

Collected by Messrs. Reade and Cobbold at Church Stretton, Shropshire, in July, 1907.

No. 1 and 2.—These were duplicates of *Buxton Rock from Castle Hill, All Stretton*, and were slightly weathered externally. The rock was very hard, of fine texture, and had a greenish-grey quite smooth homogeneous fracture. The analysis was made on a composite (equal weights) of Nos. 1 and 2. The total weight of the specimen was 9 oz.

No. 3.—*A partly-weathered calcareous nodule, found loose by the roadside, but certainly from the Stretton Shales.* A close textured dark grey rock, with a few brown cavities.

The fracture was crystalline, and the surface effervesced when touched with acid.

More than half its weight is $CaCO_3$.

No. 4.—*A gritty slate from beds in the dingle below High Park.* A dark purple, partially fissile rock of fine texture. Small flakes of mica, very noticeable with a lens in the crushed powder.

No. 5.—*A grit from beds in the dingle below High Park.* A dark grey rock of decidedly coarser texture than No. 4.

The constituent materials shew the rock to have been much compressed.

No. 6.—*Red Conglomerate from corner of roads below High Park, known as the Huxter Conglomerate.* The specimen contained a few small angular pebbles, which became free on smashing the rock.

No. 7.—*Purple Shale with spots from the Burway, ½-mile west of the Devil's Mouth.* An extremely fine textured purple rock, imperfectly fissile. The so-called spots appear to be slight elevations of the surface.

NOTE.—All the preceding were collected by Mr. Cobbold in Mr. Reade's presence, during a drive over the Longmynd.

No. 8.—*Stretton Shale from a house excavation above Halescroft, Madeira Walk,* collected by Mr. Reade. A fine textured dark grey fissile slab. The rock is traversed by a system of jointing, which helps to break it up into small regular fragments.

No. 9.—*A nodule in the above shales showing cone-in-cone structure. Collected by Mr. Cobbold.* This appears to be a conglomerate, for here and there were small round pebbles, with casts of same on fractured surfaces.

No. 10.—*A specimen of the Batch Volcanic from the third ford above the Carding Mill.* It weighed 1 lb. 9 oz., and was collected by Mr. Cobbold. Shews flaky compression of constituents.

No. 11.—*A purple shale (slate?) from above the Carding Mill.* A very fine textured soft rock, such as would be produced by consolidation of a somewhat ferruginous mud.

GENERAL REMARKS.

The preceding sketch of the salient features and comparative characteristics of the Longmyndian rocks disclosed by our analyses is quite consistent with their volcanic origin. Though they present great variations of texture, the series, as a whole, throughout an immense thickness is of a similar mineralogical character, and this is brought out pretty fully by the chemical investigation.

The beds, as a whole, dip at very high angles to the westward. They are sometimes vertical and occasionally overturned bringing the dip to the east, and in other and rarer cases form portions of anticlines.

A peculiar feature of the Longmyndians is the concentration of the lime in the Stretton shales. In No. 8, the parent rock, the lime is only 0·22 per cent., whereas, in a nodule, No. 3 of the Table, it reaches 30·54 per cent. Cone-in-cone structure is more or less an accompanying development. The occurrence of phosphates in these beds is no sure criterion of pre-existent organic life, inasmuch as phosphates are accessory minerals in basalt and other plutonic rocks. In the Welsh Cambrians phosphates occur which on the other hand may be referable to aquatic forms, for casts of organisms are met with in these rocks. Seeing that the composition of the Longmyndians, as a whole, presents some of the chief characteristics of slate rock, we may ask why it is that slaty cleavage should be so little developed on this horizon.

A partial answer will be that though the finer textured rocks in the Longmyndians have most of the qualities for slate production, many of the beds have far too gritty and too coarse a texture for conversion to slate rock. Apart, however, from grittiness the intercalation of beds of soft material with those of hard structure will have impeded the free play of those dynamic forces whereby the energy required to convert the rock-forming minerals of a sediment into slate is developed. In parts of the Longmynd country we do, however, find cleavable slate mixed with grits of a broken character, as can be seen at the Carding Mill.

Though the ultimate composition of the Ludlow Old Red Marl may in cases be like the Longmyndian shales, if we compare them in the field, we find that the marl shows no sign of cleavage. It is nearly horizontal and

has not been subject to any great lateral pressure. Thus a tectonic comparison bears out the theory that *pressure* is one of the agencies if not the chief one concerned in the production and development of slaty cleavage. Another question which presents itself to an enquiring mind is the cause of *plasticity* in some sediments. Why, in the case of rocks of the same chemical composition, should one be plastic and capable of being moulded to artistic forms on the potter's wheel, whereas another is *non*-plastic and has so little structural adhesion of constituent particles that if placed in water it quickly crumbles to pieces?

The Longmyndian rocks are none of them plastic now, but many have been hardened and have lost a plasticity they perhaps at one time possessed.

Some physicists contend that plasticity is a mechanical effect and depends on the minute sub-division of constituent particles so that any mineral powder should become plastic on wetting, provided the particles be fine enough. This is not so, however, with slate dust for it does not become really plastic when wetted. On the other hand, quite plastic clay does result from natural weathering of hard slaty shales. Here, of course, we have a chemical process at work, viz., the hydration of the alumino-ferric, magnesian, and other silicates of the shales, which gives clay as a product.

The physics of plasticity in clay must surely be closely connected with the nature of the mineral silicates, the degree of their hydration, and their predominance over the sand. One of us a few years ago had occasion to examine a bed of supposed fuller's earth at Bethesda, Caernarvonshire. It was of very fine texture and possessed very slight plasticity. An examination proved it to be a glacial deposit made up of ground slate rock holding minute fragments of various rocks of undoubted glacial

origin. It was not more plastic than is some of the fine mud from the bed of a glacier stream, for here, though the comminution of the rock minerals is always extreme, the conversion of them into clay has not come about. The conversion is slow—a function of the ages in fact.

In concluding the paper, we may express a hope that though we have to a large extent been only breaking fresh ground, our observations, taken in conjunction with the work already done by the eminent geologists we have quoted, may prove of value in assisting to penetrate the mystery at present surrounding the history of the Longmynd.

ANALYSES.

D. in the Shales ng Cone re.	No. 10. The Batch Volcanics from 3rd ford above the Carding Mill.	No. 11. Purple Shale or Slate? from above the Carding Mill.	
0	59·40	62·93	Silica.
7	0·55	0·62	Titanic Oxide.
6	19·57	17·88	Alumina.
0	3·89	6·24	Ferric Oxide.
5	2·18	1·23	Ferrous Oxide.
0	0·09	0·14	Manganous Oxide.
3	5·22	1·02	Lime.
e	—	—	Baryta.
7	2·28	2·10	Magnesia.
6	2·47	3·38	Potash.
8	1·22	1·77	Soda.
4	trace	trace	Phosphoric Acid.
8 b	present	none	Carbonic Acid.
5	0·03	none	Sulphuric Acid.
1	3·10	2·69	
0	100·00	100·00	

just detectable.

PROCEEDINGS

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(The Authors having revised their own Papers, are alone responsible for the facts and opinions expressed in them.)

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